

This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

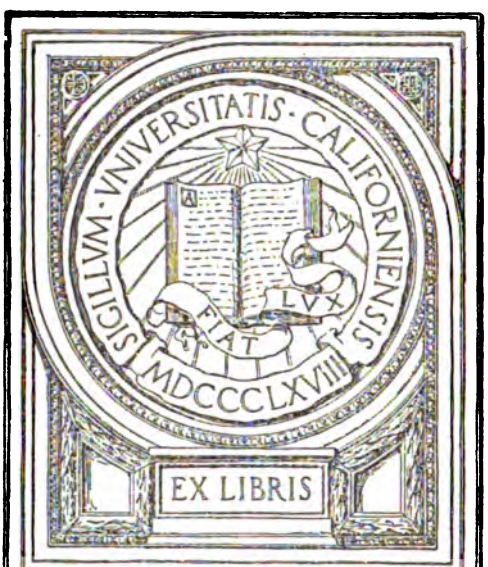
+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`



MECHANICS DEPT.

Engineering
Library

AMERICAN FUELS

VOLUME II

McGraw-Hill Book Co. Inc.
PUBLISHERS OF BOOKS FOR
Electrical World ▿ Engineering News-Record
Power ▿ Engineering and Mining Journal-Press
Chemical and Metallurgical Engineering
Electric Railway Journal ▿ Coal Age
American Machinist ▿ Ingenieria Internacional
Electrical Merchandising ▿ BusTransportation
Journal of Electricity and Western Industry
Industrial Engineer

AMERICAN FUELS

IN TWO VOLUMES
VOLUME II

BY

RAYMOND FOSS BACON, PH.D., SC.D.,

CONSULTING CHEMICAL ENGINEER, NEW YORK, N. Y.; FORMERLY DIRECTOR OF THE MELLON INSTITUTE OF INDUSTRIAL RESEARCH OF THE UNIVERSITY OF PITTSBURGH

AND

WILLIAM ALLEN HAMOR, M.A.,

ASSISTANT DIRECTOR OF THE MELLON INSTITUTE OF INDUSTRIAL RESEARCH

WITH THE COLLABORATION OF SPECIALISTS

FIRST EDITION

McGRAW-HILL BOOK COMPANY, INC.
NEW YORK: 370 SEVENTH AVENUE
LONDON: 6 & 8 BOUVERIE ST., E. C. 4
1922

TP318
B2-
V.2.
Engineering
Library

COPYRIGHT, 1922, BY THE
MCGRAW-HILL BOOK COMPANY, INC.

THE MAPLE PRESS YORK PA

CONTENTS

VOLUME II

CHAPTER VIII (*Continued*)

PAGE

FINELY DIVIDED FUEL, BY F. PARKMAN COFFIN 629

CHAPTER IX

THE DEVELOPMENT OF MECHANICAL STOKERS, BY A. W. SMELTZ . . 757

CHAPTER X

THE USE OF WOOD FOR FUEL. 785

CHAPTER XI

FUEL OIL AND ITS UTILIZATION, BY B. STANLEY NELSON 794

CHAPTER XII

COLLOIDAL FUEL, BY LINDELL T. BATES 880

CHAPTER XIII

NATURAL GAS, BY SAMUEL S. WYER 902

CHAPTER XIV

PRODUCER GAS TECHNOLOGY, BY F. W. STEERE 914

CHAPTER XV

WATER GAS, BY A. E. BLAKE 995

CHAPTER XVI

BLAST FURNACE GAS, BY J. M. CAMP AND C. B. FRANCIS. 1016

CHAPTER XVII

THE DAYTON PROCESS, BY F. C. BINNALL. 1036

CHAPTER XVIII

THE RELATIVE VALUES OF GASEOUS FUELS, BY F. C. BINNALL . . . 1050

56...5.9

CHAPTER XIX

PAGE
SURFACE COMBUSTION, BY A. E. BLAKE 1068

CHAPTER XX

THE FUTURE OF THE ARTIFICIAL GAS INDUSTRY, BY F. C. WEBER . . 1095

CHAPTER XXI

HEAT APPLICATION, BY D. K. BULLENS 1107

CHAPTER XXII

THE RELATIVE THERMAL ECONOMY OF ELECTRIC AND FUEL-FIRED FURNACES, BY E. F. COLLINS 1122

CHAPTER XXIII

THE ECONOMICS OF AMERICAN POWER PRACTICE, BY CHESTER G. GILBERT AND JOSEPH E. POGUE 1135

CHAPTER XXIV

FUEL CONSERVATION, PRESENT AND FUTURE, BY HORACE C. PORTER 1151

CHAPTER XXV

SOME PROBLEMS IN THE UTILIZATION OF FUELS, BY RAYMOND F. BACON AND WILLIAM A. HAMOR 1165

CHAPTER XXVI

THE PROBLEMS OF THE PETROLEUM INDUSTRY, BY WILLIAM A. HAMOR 1190

APPENDICES

APPENDIX I: METHODS FOR THE ANALYSIS OF COAL 1214
APPENDIX II: METHODS FOR TESTING FUEL OILS AND SPECIFICATIONS FOR FUEL OILS 1235

INDEX 1245

UNIV. OF CALIFORNIA

AMERICAN FUELS

VOLUME II

CHAPTER VIII (*Continued*)

THE TRENT PROCESS

Washing and Pulverizing.—In this process coal is purified after pulverizing to about a 200-mesh product, which is sufficiently fine to physically detach much of the inorganic mineral matter from the coal particles.

The coal will first be crushed to a maximum size of ⅜ or ½ in. and then fed to tube mills for wet grinding. Coals containing a high percentage of inert mineral matter can be given a preliminary cleaning by a hydraulic method, after crushing, to avoid the necessity of pulverizing all of the impurities. With some coals, however, the crushed material will not be sufficiently divided to separate very much of the inert mineral matter from the coal and it will be desirable to pass the coal through the mill once in order to granulate it. Closed-circuit grinding (page 594) can be used and the oversize material from the settling tank, or classifier, can be cleaned by a hydraulic method before returning it to the mill, as has been done in milling certain ores.

Amalgamation with Oil.—The sludge of pulverized coal suspended in water is then run into a tank, where oil is gradually added and the mixture is rapidly agitated or stirred. At a certain point in the course of adding the oil, the coal and oil

agglomerate into an amalgam, from which most of the water and ash are excluded. When the amalgamation is effected in a glass jar, the sudden change in the appearance of the black sludge is quite striking as the amalgam separates from the water which is laden with finely divided grey ash. The amalgam forms in small globules which resemble cream cheese, or caviar, except that they are black, the interstices being filled with water carrying fine gray mineral sands in suspension. The water and sand are then drained off, and the amalgam is agitated and washed with clean water to remove any sand particles which may adhere to the surface or be trapped in water pockets.

Upon further agitation, the globules of amalgam consolidate into a pasty mass which often contains as little as 10 per cent. of water. After standing for a day or so, most of the remaining water drains off or evaporates, leaving possibly 2 or 3 per cent of moisture in the amalgam.

The proportion of oil in the amalgam made from bituminous coal is about 30 per cent, but it varies with different coals and may be said, roughly, to average 1 part of oil to 2 of coal. A wide variety of mineral oils have been used, ranging from light oils to heavy oils, the latter being preferred owing to their lower cost. The oil can be recovered by distillation at temperatures below those at which volatile matter is distilled from the coal in appreciable quantities. This is carried on in a tubular metal retort through which the amalgam is advanced by a worm, and the coal is recovered in a dry pulverized state. In this form it should be particularly applicable for firing metallurgical furnaces, where ash and slag deposits are objectionable.

The ash and slag problems in boiler furnaces will also be simplified by the use of clean pulverized coal.

Results of Cleaning.—The cleaning process has been applied to samples of more than 250 coals, including anthracite, bituminous coal and lignite. The results vary with every coal; some containing 15 per cent of ash are reduced to 7 per cent, other coals containing 25 per cent are reduced to 3 per cent ash content. The results attained with certain coals are given below. Some of those with high-ash content were treated by the hydraulic and oil-amalgamation processes in succession.

REDUCTION IN ASH CONTENT

Eastern Bituminous Coals

Sample No.	Source	Ash content (per cent)	
		Raw coal	Clean coal
39	Pennsylvania	12.5	6.5
40	Pennsylvania	29.6	2.1
41	Pennsylvania	12.5	3.4
42	Pennsylvania	37.0	8.0
27	Barking, Pa.	35.0	18.0
166	Pittsburgh, Pa.	26.7	12.0
46	Clinchfield, Va., slack	12.4	5.0
47	Clinchfield, Va., No. 4 seam	8.0	3.8
48	Clinchfield, Va., Upper Banner	6.2	3.6
49	Clinchfield, Va., Lower Banner	4.4	3.5
174	Richmond Basin, Va.	10.7	4.1
175	Richmond Basin, Va., screenings	26.5	3.5
141	West Virginia (?)	10.4	4.5
143	Samples of coal used by steel mill in Ohio	10.3	6.0
135		7.1	3.7
137		6.5	4.7
138		6.5	3.0
142		4.5	3.0
136	Novcono, Ohio	4.1	1.3
22	Culm, exterior of pile	72.5	2.7
23	Culm, interior of pile	43.5	6.3
31	Kentucky	2.3	1.0
32	Kentucky	5.1	2.4
28	Benton, Ill.	10.2	3.0
72	Vandalia, Ill.	37.0	2.6
73	Vandalia, Ill.	28.0	3.0
147	Illinois	9.0	2.0
67	Illinois, washery sludge	12.0	3.2
	By-product Fuels		
148	Coke breeze	14.6	4.8
69	Ash from hand-fired boiler	93.5	9.7
70	Ash from stoker	76.2	9.1

REDUCTION IN ASH CONTENT
Western Coals

Sample No.	Source	Ash content (per cent)	
		Original	Final
	Bituminous Coal		
170	Frontenac, Kan.	22.5	3.7
171	Raton, N. M.	19.5	7.5
12	Tonopah, Nev.	29.0	9.4
26	Couldale, Nev.	25.3	12.5
80	Nevada	7.0	3.3
91	Colorado	18.8	8.6
172	Stone Canyon, Cal.	6.5	3.7
24	Stone Canyon, Cal.	10.2	6.5
20	British Columbia	16.0	5.2

REDUCTION IN ASH CONTENT
Foreign Bituminous Coals

	England		
114	Washery sludge	30.0	1.2
107	Yorkshire	12.5	3.5
109	Hardwick	12.2	2.7
110	Durham	9.4	4.0
108	Silver Hill	6.5	1.4
	Japan		
113		16.0	5.6
120		16.5	7.0
	Peru		
112		36.8	13.8
115		38.6	11.4
	Brazil		
129	Subbituminous from Rio Grande	34.0	8.6
		34.0	5.4
117	Subbituminous from Sul	30.0	10.4

All these coals were ground wet. In many cases, similar samples were pulverized dry and then mixed with water, but the results were not as good as those attained by wet grinding, less ash being removed. With some coals it has, apparently, been possible to reduce the ash content to a value which corresponds with the intrinsic ash which is partly of organic origin. In other cases, the extraneous mineral matter was too intimately

associated with carbonaceous matter to allow of such complete separation.

Laboratory Studies by the U. S. Bureau of Mines.*—A comprehensive series of laboratory investigations of the underlying chemical and physical phenomena in the Trent process has been carried out by the U. S. Bureau of Mines. The results attained in the cleaning of small samples of coal are summarized below.†

Tests made with a number of typical coals of the United States gave an ash reduction varying from 30 to 75 per cent. Sulphur reduction was fairly good in the case of anthracites, but low in the case of bituminous coals. Combustible recovery was, with a few exceptions, better than 95 per cent. Results point to the desirability of preliminary water concentration of high-sulphur coals for removal of pyrite before treatment by the Trent process. It has been found that grinding finer than 200-mesh does not give sufficiently greater ash reduction to pay for the increased cost of finer pulverization.

Amalgamation of Hydrocarbons.—The physical reaction involved in the formation of the amalgam has been found to take place between most of the liquid hydrocarbons and the solid bituminous or carbonaceous minerals. The results attained with various oils, together with the general principles involved in the process, are summarized as follows in the report.

A new technology had previously been given to ore preparation by the use of small quantities of oil in water with froth flotation, and although the methods, results and mixtures of the Trent process were quite different, yet the same physical phenomena of differential wetting were used, and the possibility of there being interesting results in fuel technology was evident.

Any oil or organic liquid not miscible with water may be employed in the Trent process, provided its viscosity is not too great. The heavy topped crudes may be employed if the water used in the process is heated, thus reducing the viscosity of the oil. Certain commercial emulsions, such as water gas tar or "B.S." petroleum emulsions, have been successfully employed. Here again the viscosity must not be too great. B.S. (base sediment) refinery settlings of the consistency of cup grease were not found to be satisfactory at ordinary temperatures An oil of viscosity equal to 135 seconds (at 25°C.) on the Saybolt viscosimeter gives satisfactory results. When oils of viscosity equal to 400 seconds and upwards are

* "Laboratory Studies of the Trent Process," by G. St. J. PERROTT and S. P. KINNEY, with introduction by O. P. HOOD, U. S. Bureau of Mines, 1921, Serial No. 2263.

† From *Power*, **54** (1921), 196.

employed, it is necessary to employ heated water to secure the best results. Using an oil with a viscosity equivalent to 4,000 seconds Saybolt, at room temperature, it was found necessary to heat the water to 70°C. to effect formation of the amalgam.

Apparently the efficiency of ash separation begins to diminish when an oil greater in viscosity than about 40 seconds Saybolt is employed. Combustible loss in the refuse is somewhat less with the more viscous oils. Considerably more of the liquids of low viscosity, such as benzol and carbon tetrachloride, must be used to obtain a coherent amalgam than of the oils of higher viscosity.

In the greater part of the work, oil has been used in an amount equal to 0.3 lb. per pound of dry cleaned coal. If a coal contains 25 per cent of removable refuse, it will be necessary to use 450 lbs., or about 62 gallons, of a light fuel oil per ton of raw coal treated. With coal ground to pass a 200-mesh screen, this quantity of oil produces an amalgam in granules about 18 inch in diameter. If finer ground coal is employed, it may be necessary to use as much as 0.4 lb. of oil per pound of dry cleaned coal. It is best to work with as small an amount of oil as possible, because better washing of the amalgam is possible when the granules are fairly small, and the resultant cleaned coal contains less ash.

Although at first sight it might be thought that considerable oil would be lost as a result of emulsification in the water, experiments have shown no appreciable loss due to this cause. Apparently the presence of finely pulverized coal in the water effectively prevents emulsification. As a matter of fact, certain commercial emulsions, such as water-gas tar and B.S. emulsion, are broken down by the addition of pulverized coal and may be used as oils for carrying out the Trent process. Even if a certain amount of oil were retained in the water, the use of this water over again, after separation of the refuse, would eliminate loss from this source.

The oil retained by the refuse is seldom more than 1 per cent of the total oil used and frequently is practically zero. In certain cases where a large amount of refuse high in carbon and pyrite has been removed, the oil absorbed in this refuse has been as much as 10 or 15 per cent of the total oil used.

An amalgam in granules one-eighth inch or larger usually retains 8 to 12 per cent of moisture which will not drain out of the mixture, in addition to the hygroscopic moisture of the coal. It has been found possible to reduce this moisture to about 5 per cent by passing through a kneading machine of the meat-chopper type. In an amalgam of very fine granules, the moisture content may be as high as 30 or 40 per cent. A large part of this moisture occurs as a coating of the small particles and is separated by further agitation or the addition of more oil to effect the formation of larger granules. The size of the granules depends upon the amount of oil used, the size of the coal particles, the method of agitation and time of agitation, and to some extent on the character of the coal. Certain subbituminous coals require more oil to produce granules of a given size than do the bituminous coals or anthracite.

Brisk agitation of the kind given by rapidly revolving paddle blades is most efficient in separating mineral matter from coal and in securing rapid

formation of the amalgam. Coals differ very much in the rapidity with which they form the so-called amalgam. As a general rule, it may be stated that coals containing more than 3 or 4 per cent of hygroscopic moisture as received will be difficult to work. When they contain 20 or 30 per cent moisture, as do the lignites, separation is practically impossible, even with prolonged agitation.

It has not been found possible to get good separation of carbonaceous material from mineral matter by treatment of the raw lignite. Lignites are very readily wetted by water, and once the lignite is well wetted with water, either by wet grinding or by soaking, the water is not readily displaced by oil. On agitation of a wet ground mixture of lignite with oil, there is some tendency for separation into layers of coal-oil and refuse-water, but no formation of the compact agglomerate of coal and oil which takes place with bituminous coals or anthracites. Microscopic examination of the mixture shows globules of oil suspended in the mixture of lignite and water, indicating a high surface tension between the oil and the coal-water mixture.

If an oil is used which can be distilled at a temperature below the distilling temperature of the coal, powdered fuel is reclaimed from the amalgam and the oil may be reused. If a heavy oil be used and distilled to dryness, a coke product may be recovered, although the coal used may have had no coking quality. If the distillation proceed only to a heavy pitch, a mass suitable for briquetting may be made.

Experiments made by the U. S. Bureau of Mines indicate that the oils distilled from the finely divided coal in the amalgam will give a greater yield of gasoline than when distilled from the liquid at atmospheric pressure. The increase corresponds with the yield obtained when the same crude oil is distilled under pressure, the total distillate showing an increase of about 6 per cent, a large part of this increase being in the light oil fraction (see page 628). Apparently, the surface tension on the small particles is equivalent in its effect to a higher pressure and the process should be a valuable method for cracking oils.

Utilization of the Products.—The use of the raw amalgam as boiler fuel is mentioned on page 674 and its application as fuel for ships and for building heating plants has been presented in Chap. V. Its use as gas-making fuel is mentioned on page 374. The process can also be used for cleaning coal for further preparation by distillation, the amalgam being utilized for making metallurgical coke or for distillation at low temperature, as discussed on page 479.

This process originated from some experimental work undertaken by the inventor, Walter Trent, in connection with a constant-pressure cycle engine. This was first developed for burning oil under pressure in a separate combustion chamber and

the desirability of being able to burn pulverized coal led to the development of a method for removing much of the ash during the preparation of the fuel. The experimental work on the engine is to be continued, but most of the development work which has been done by the Trent Process Corporation* has been concentrated on the process for the cleaning of coal.

THE CONVEYING OF PULVERIZED COAL

The ease with which pulverized fuel may be conveyed from the preparation plant to the furnaces is one of the marked advantages resulting from its mobile properties. Four general methods are in use:

1. Screw conveyors.
2. Pneumatic mass systems.
3. Pneumatic suspension systems.
4. Conveying in bulk, by tank cars, barges, etc.

1. Screw Conveyors.—The screw conveyor has been used in cement mills for so long a period that it lacks the novelty associated with the other systems. It is a long spiral rotating in a metal trough with a removable top. When used for pulverized coal, the trough should be made of a material which is not affected by the sulphur in the coal. Cast-iron housings, properly machined for alignment, have proved very satisfactory. The commercial sizes and capacities are given in Table LXXXVII.

TABLE LXXXVII

DIAMETER OF SCREW, INCHES	CAPACITY, TONS OF COAL PER HOUR
7	8
8	15
9	20
10	26
12	45
14	60
16	95

The power required is practically constant for all sizes and can be roughly taken as $\frac{1}{8}$ hp.-hr. per ton, per 100 ft. of length. The most advantageous field for the screw conveyor is in cases where a large amount of fuel is to be conveyed over a relatively short distance. Under these conditions, it requires less power than pneumatic conveyors.

*1440 U St. N. W., Washington, D. C.

Some of its limitations are as follows:

(*a*) The individual sections are limited to a length of 200 ft. and the sections for conveying coal between buildings must usually be mounted on a trestle.

(*b*) The slope cannot exceed about 15° without danger of flushing (*i.e.*, sliding of the coal without regard to the motion of the screw).

(*c*) The low speed of the screw requires the use of belts, gears and countershafts for the motor drive.

(*d*) A new section of conveyor is required for every change of direction, or an elevator for considerable changes in elevation. The sections must be electrically interlocked to ensure of starting and stopping in proper sequence to avoid plugging with coal.

(*e*) It contains moving parts which require attention and lubrication.

In some of the older plants considerable dust escapes from the joints. In modern installations, however, this is provided against by proper construction of the conveyor trough and by furnishing air vents (with provision for collecting dust) where pressure may be developed. There is no great difficulty in making them tight. The various limitations, however, have encouraged the development of pneumatic methods for conveying coal through pipes.

2. Pneumatic Mass Conveying.—This consists in forcing pulverized coal to flow through pipes by the application of pneumatic pressure. The various methods may be subdivided as follows, in the historical order of their development:

(*a*) Non-aerated flow from a blowing tank.

(*b*) Aerated flow from a blowing tank.

(*c*) Aerated flow from a feed screw.

(*a*) The pneumatic conveying of finely divided materials *en masse* has been practiced for many years in connection with plaster of paris and sand. Pressure tanks have been used for elevating sand at railroad terminals and this system was installed for conveying pulverized coal, about the year 1914, in the Schenectady works of the General Electric Co. The coal was put in a blowing tank and compressed air was applied on top of the coal, which was discharged through a 3-in. pipe leading from the bottom of the tank to a boiler 700 ft. distant. An air pressure of 50 lbs. was used to start the coal moving and this pressure fell off as the air expanded with the displacement of

the coal. No especial attempt was made to aerate the column of coal and thus increase its fluidity, the air present in the voids being relied upon.

The Holbeck high-pressure distributing system operates on this general principle. It is used for distributing coal from a milling plant to sub-stations, in different departments of a manufacturing plant, from which it is distributed locally to groups of metallurgical furnaces by a low-pressure system carrying the coal in suspension. The blowing tank is filled about three-quarters full; and the filling and discharging require 10 or 15 min., 3 tons of coal being sent at each charge. The air requirements range from 0.5 to 1.0 cu. ft. of free air per pound of coal, and this is compressed to pressures ranging from 30 to 100 lb., according to the distance and other factors. This equipment is manufactured by the Bonnot Company and is used in connection with other parts of the Holbeck system.

(*b*) *The Quigley high-pressure air transport system* was originally developed at the Schenectady works of the American Locomotive Co., where it was first used, and the patent rights have been acquired by the Quigley Furnace Specialities Co.,* which has further perfected the details. One of the distinctive features is the aeration of the column of coal as it leaves the blowing tank. This system is being used very successfully in several steel plants, for distributing pulverized coal from the milling plant directly to the bins located at the various furnaces. The pulverized coal is fed from an enclosed bin to one or more blowing tanks shown in Fig. 136. These are mounted on platform scales, for weighing each charge of coal, and are alternately filled and discharged into the pipe-line by applying compressed air on top of the coal. The discharge pipes hang vertically from the top of each tank to within a few inches of the bottom. A larger curtain pipe surrounds the discharge pipe, within the tank and is open at the top and bottom to allow the air to reach the open lower end of the discharge pipe, where it helps to entrain and aerate the coal. The air forces the whole mass of coal slowly downward while it is being discharged upward through the pipe in the form of alternate slugs of coal and air, the air being supplied by the curtain pipe. A sort of pulsometer action takes place between the coal and air as they enter the discharge pipe. This is caused by the building up of

* 26 Cortlandt St., New York, N. Y.

static pressure until the coal slug reaches a length of about six feet. Then air cuts in beneath the coal and flows until the excess pressure is relieved. The coal is finally discharged from the top of the tank through a switch valve into the horizontal pipe.

The pipe line may be run overhead or underground, using ordinary 3- or 4-in. screwed piping and long bends, and is free



FIG. 136.—Pair of blowing tanks, mounted on platform scales, for Quigley air-transport system.

from the limitations of screw conveyors. The bins at the various furnaces are fed by branch pipes equipped with switch valves and cyclone separators. The coal is discharged through the separators and the air is vented away with the loss of an extremely small amount of dust. A switch valve is shown in Fig. 137. It may be operated from the floor by means of a chain, or automatically from the blowing tanks. For semi-

automatic operation each switch valve is equipped with a spring release and a solenoid controlled catch, and is operated by a push button at the mill house. The mill attendant goes the round of the bins at the furnaces, notes the quantity required at each bin, sets the switch valve to "supply" and returns to his blowing tanks. Then he proceeds to send the required amount of coal to each tank, being guided by the indications of the dial on the scales, which enable him to start and stop the movement of coal at the desired points.

In the full automatic switch control, a specially designed equipment, furnished for each bin, automatically sets the

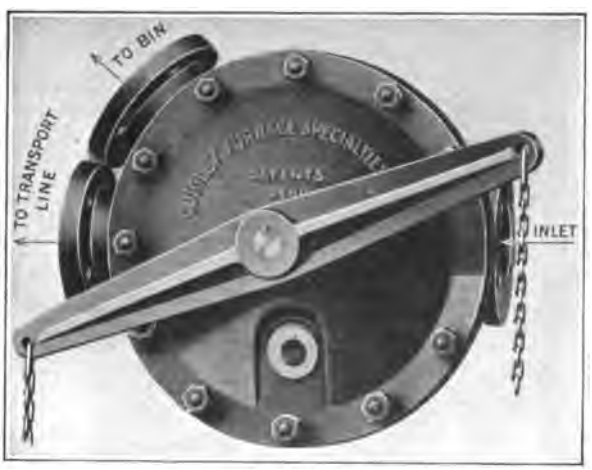


FIG 137.—Switching valve set for transport line.

switching valve when fuel is needed, and a signal light at the blowing tank notifies the fuel distributor. When the proper amount has been transported to the bin, the signal goes out and the valve is automatically reset to the line.

The blowing tanks are built in capacities ranging from 1 to 8 tons and may be filled to capacity and discharged intermittently to the various bins. After each blow, the residual air in the tank may be discharged through the line to clear it by simply lowering the curtain-pipe. To provide for stoppage due to moisture in the coal, or condensation in the pipe, a small companion pipe is installed in parallel and is connected to the main pipe by "bleeders" at suitable intervals. This may be used for injecting compressed air to break up and clear any

stoppage of coal. The aeration of the column of coal as it leaves the tank renders it possible to loosen and discharge the coal, even though it be tightly packed in the tank. This may be the case when the coal is left standing for a number of days, during which it is subject to vibration from drop hammers, etc.

The air is compressed to 100 lb. per square inch and then expanded to the pressure required to start the coal. This pressure varies according to the distance, the maximum being about 50 lb.

Pulverized coal is being blown through 4-in. pipes for various distances up to 1,700 ft. and the rate of delivery is about 4 tons in 5 min.

The air requirements in this system are 1 cu. ft. of free air for each 1.5 to 2.0 lb. of coal transferred, By using multiple blowing tanks and an air compressor with a piston displacement of 2,000. cu. ft. per minute, about 50 tons of coal could be delivered per hour through a 4-in. pipe line.

The general plan of the Quigley system is shown in Fig. 138, which includes a milling plant equipped with a Ruggles-Coles dryer and Raymond mill, together with the air transport system* and furnaces.

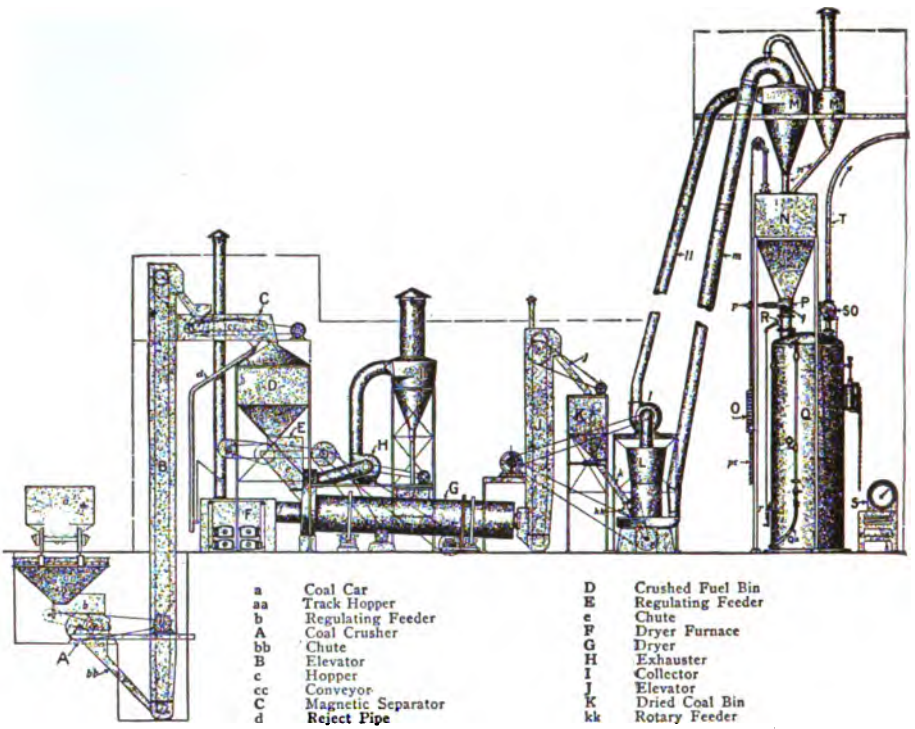
Arrowood System.—An air-transport system has recently been developed by the Ground Coal Engineering Co. (Chicago). The first installation was started with an initial pressure of 60 to 70 lbs. per sq. in., expanding to atmospheric pressure at the end of the blow. Using these pressures, coal was conveyed through a 4-inch pipe at the rate of about 3 tons per minute. The pipe contained several bends, a 20 ft. drop and a 25 ft. lift.

(*c*) *The Fuller-Kinyon pulverized material conveying system* has been more recently developed by the Fuller-Lehigh Co.† This differs from the systems described above in that no air pressure is applied to the bin at the milling plant, the coal being pumped into the pipe line by a short feed screw and then aerated by the injection of a relatively small amount of compressed air.

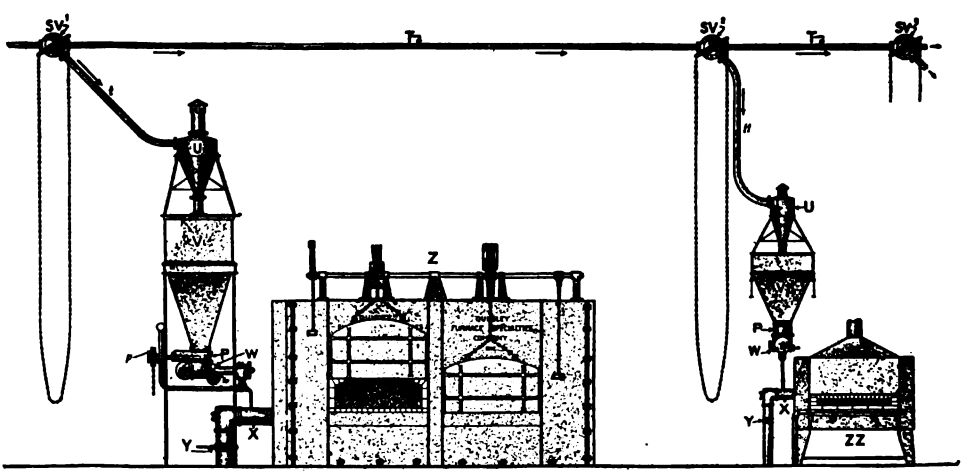
The feed screw or "forcing worm" is located at the bottom of the "pump hopper," which is preferably located to be fed by

* Consult: "A New Method of Burning Powdered Coal," *Iron Age*, Feb. 28, **1918.** "Handling Powdered Coal as a Fluid," by H. A. KIMBER, *Eng. World*, Jan. 1, **1919.** See also references on pages 654 and 656. The authors are indebted to H. A. KIMBER, W. O. RENKIN and H. F. MATHEWS, of the Quigley Furnace Specialties Co., for much information in regard to the handling and utilization of pulverized coal.

† Fullerton, Pa.

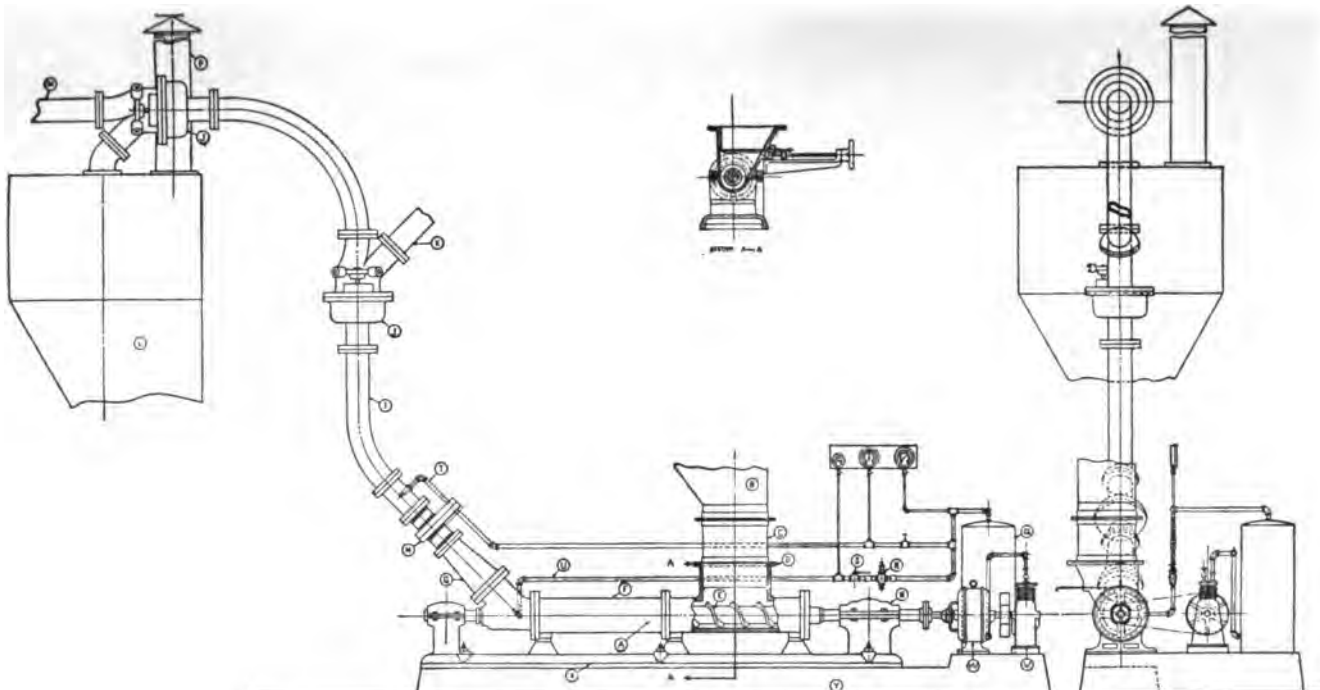


a	Coal Car	D	Crushed Fuel Bin
aa	Track Hopper	E	Regulating Feeder
b	Regulating Feeder	e	Chute
A	Coal Crusher	F	Dryer Furnace
bb	Chute	G	Dryer
B	Elevator	H	Exhauster
c	Hopper	I	Collector
cc	Conveyor	J	Elevator
C	Magnetic Separator	K	Dried Coal Bin
d	Reject Pipe	kk	Rotary Feeder



L	Pulverizer	pc	Hand Chain	tt	Branch Fuel Line
l	Exhauster	Q	Blowing Tank	U	Collectors
ll	Discharge Pipe	Qa	Compressed Air Supply	V	Furnace Bins
M	Collector	q	Flexible Connection	W	Fuel Feed Controller
M2	Secondary Collector	R	Inlet Valve	w	Fuel Regulating Wheel
m	Return Air Pipe	S	Scale Dial	X	Burner
N	Pulverized Fuel Bin.	SO	Shut Off Valve	x	Primary Air Pipe to Burner
O	Fuel Bin Gauge Indicator	SV	Switching Valves	Y	Combustion Air Blast Gate
P	Dust Tight Gate	T	Transport Line	Z	Double Door Heating Furnace
p	Hand Chain Wheel	t	Branch Fuel Line	ZZ	End Heating Forge Furnace

FIG. 138.—Quigley powdered coal milling plant and air transport system.



"A" Fuller-Kinyon 6" Pulverized Material Pump. "B" Material Bin. "C" Supply Spout. "D" Pump Hopper. "E" Forcing Worm. "F" Pump Barrel.
"G" Reducing Nozzle. "H" Single Diverting Valve. "I" Convertor Conduit. "J" Two-Way S. K. Valve "K" Branch Conveyor. "L" Receiving Bin.
"M" Continuation of Conveyor. "N" Main Bearing. "P" Vent Stack to Receiving Bin. "Q" Air Receiver "R" Pressure Reducing Valve. "S" Air Valve.
"T" Conduit Clearing Air Line. "U" Airating Line. "V" Air Compressor. "W" Electric Motor. "X" Pump Base. "Y" Foundation.

FIG. 139.—The Fuller Kinyon pulverized material conveying system.

gravity from the pulverizer. The worm is directly connected to an electric motor and forces the coal into a large reducing nozzle, where it is aerated, by a circle of jets, just as it leaves the worm. Beyond the nozzle is a valve which can be closed while the pipe line is being blown out with air, admitted for this purpose beyond the valve whose function is to prevent the air blowing back into the tank.

The coal is distributed to the various furnace bins by diverting valves in the line. These are double-ported slide valves which are closed by a flat plate with tapered edges and this is pivoted to rock in such a way as to close off either the branch or the main line beyond the furnace bin to be filled. Each bin is provided with a vent pipe, but no cyclone is considered necessary owing to the small amount of air used.

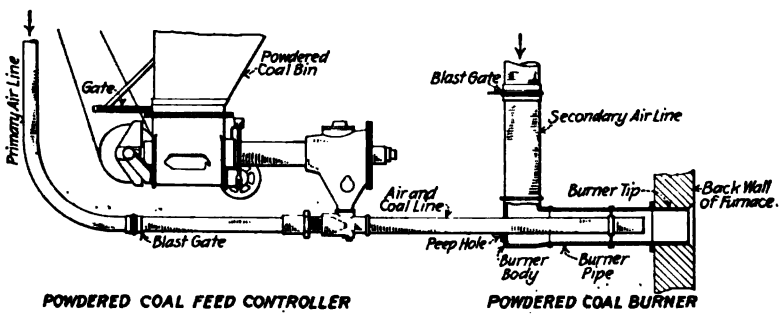


FIG. 140.—Quigley burner system for pulverized fuel.

Approximately 8 cu. ft. of free air are required for aerating 1 cu. ft. of coal. As loose pulverized coal weighs about 38 lb. per cubic foot, the air requirements are slightly more than 2 cu. ft. for each 10 lb. of coal handled. The air pressure necessarily increases with the distance the material is pumped and varies from 5 lb., for a horizontal distance of 100 ft., to 45 lb. for a horizontal distance of 1,250 ft. A vertical lift in the pipe, of course, puts heavier duty on the pump and requires a slightly higher pressure. In one case coal is being fed from a pulverizer to a 6-in. pump and elevated 65 ft. and then conveyed horizontally for 100 ft., the air being supplied under a pressure of 25 lb.

An important installation of the Fuller-Kinyon system is located in the new Lakeside plant of the Milwaukee Electric Railway and Light Co., at St. Francis, Wis. This consists

of three 6-inch pumps delivering coal through 5-inch conduits to 26 coal bins which, in turn, serve eight boilers, each of 1,306 rated horsepower. A separate pipe line runs from each of the three pumps to the top of the bins. These main lines are 300 feet long and rise about 50 feet in that distance, the inclination being about 32°. In addition, there are branch lines leading to the pulverized coal dryers, making a total length of conveyor lines of 1,328 feet. The connection from the trunk lines to the bins is made through 45° bends having a 2-foot radius. The bends in the trunk lines are all of 4 feet radius. A valve is placed in the trunk line for each bin.

According to recent tests, from 4.5 to 6.0 hp. is required for driving each pump. Approximately 8 cu. ft. of free air, introduced at a pressure of 25 pounds, is required per cubic foot of coal, 13.6 hp. being required for compressing the air. Hence the total power for the pump and compressor is in the neighborhood of 20 horsepower. The capacity of the conveyor units varies under different conditions of feed to the pumps and ranges from 12 to 15 tons per hour. This corresponds to a power consumption of between 1.4 and 1.7 hp. hours per ton of coal conveyed, which would correspond to an electrical power consumption of from 1.2 to 1.5 kw. hours per ton.

It is evident that each general type of conveying system has its own economic field. The high-pressure pneumatic systems with blowing tanks are best adapted for conveying considerable amounts of coal over distances, or crooked routes, where the screw conveyor would be complicated. The slow moving mass pumped by a forcing worm, in its present stage of development, is especially applicable for conveying limited quantities of coal for any distance.*

3. Conveying in Suspension.—This consists in carrying the coal in suspension in a current of air moving at a high velocity and tapping off a part of the mixture for supplying each furnace. It does away with the individual furnace bins and the burner mechanism at each furnace, substituting therefor a centralized storage and feeding equipment. This method requires considerable power for the operation of the high-pressure blower, but it

* The authors are grateful to H. G. BARNHURST, A. G. KINYON, H. R. COLLINS and others, of the Fuller Engineering and Fuller-Lehigh Companies, for much information regarding the preparation, handling and use of pulverized coal.

simplifies the equipment at the furnaces by following the practice used when burning gas insofar as is possible.

The Holbeck low-pressure distributing system is the most widely used system which operates on this principle. It is shown diagrammatically in Fig. 174. The freshly pulverized coal is delivered from the vacuum separator (1) of the Bonnot mill through the exhauster (2) to the cyclone collector (3). The air returns to the pulverizer through pipe (4), while the coal drops into the central bin (5) and is withdrawn from the bottom of the latter by the feed screw (6) which is also shown in Fig. 171. This screw delivers the coal into the suction side of the high-pressure blower (7). It passes through the latter and is blown into the distributing main (8) which extends through the length of the building, or over a row of furnaces, and the individual furnaces are served by the branches (9) which are provided with gate valves at the point where they leave the main line.

The remaining coal and air, which are not used at the furnaces, pass through the return line (10) to the collector (3) and are separated. The coal returns to the bin and the air to the suction side of the blower through pipe (11), carrying with it some very fine coal, the residual air and dust being circulated again through the distributing pipe. The return of the surplus air and coal allows of maintaining a sufficient velocity in the distributing main to keep the coal in suspension regardless of the number of furnaces in operation.

The proportions used in the mixture in the distributing main are 50 cu. ft. of air to 1 lb. of coal, which is about 25 per cent of the air required for combustion. This rich mixture is non-explosive in the pipes. The additional air for combustion is supplied as secondary air, either through a separate main or by induction by the stack draught. The type of burner used is shown in Fig. 173.

The proportions of the primary mixture are held constant by the regulator shown in Fig. 172. This is known as the air indicator and consists of a weighted float which is free to move vertically in a slotted cylinder. The air, before passing through the blower, enters the cylinder at the bottom and leaves it through the slots. Variations in the volume of the air will raise or lower the float in order to increase or decrease the area of the slots through which it must escape with a constant pressure drop. A governor rod, attached to the top of the float, controls

the speed of the coal feeders by varying the position of the handle on the motor rheostat.

As previously mentioned, this system is also used for local distribution from a substation supplied by a high-pressure system. The power required for circulating the air limits the application of the low-pressure system to relatively short distances within which quite a number of furnaces are to be supplied.

The Heyl and Patterson automatic continuous system is a low-pressure distributing system in which the excess coal and air are returned to the suction side of the high-pressure blower without being separated, only the make-up coal being drawn from the central bin. This results in a minimum handling and oxidation of the fuel. The coal is drawn from the bin by means of a pneumatic siphon injector, which is operated by high-pressure air, and is mixed with the primary air in a chamber called the carbureter. The air enters the carbureter through ports whose openings are controlled by a diaphragm. The velocity of the air varies accordingly and it picks up a variable proportion of coal from a stream which circulates past the ports. The range of density is from 40 to 75 cu. ft. of air per pound of coal.

The *Kennedy-Van Saun Company* has recently designed a low-pressure distribution system which contains some original features.

4. *Conveying in Bulk.*—As previously mentioned, pulverized coal has been distributed to building heating plants in Seattle by means of tank wagons. The preparation of pulverized semi-coke at a large coal-distillation plant is a possibility of interest. Pneumatic mass conveying to large consumers may be practicable, in some instances, but it could also be widely distributed by means of barges, tank cars and automotive trucks.

BURNERS, FEEDERS AND MIXERS FOR PULVERIZED FUEL

There are so many different systems in use that they are not easily classified. They have, therefore, been subdivided in accordance with the method used for conveying the coal to the burner. The term "carrying air" is used for the air which carries the coal in suspension to a point within a few feet of the burner tip; *i.e.*, to the front of the furnace. The term "mechanical air" is used for the air supplied by blowers, as distinguished from induced air. The latter may be induced by:

(*a*) Natural draught of the stack.
(*b*) A blower between the furnace and the stack.
(*c*) Primary mechanical air.

In the last case the "primary air" is a fractional part of the total air required for combustion, the remainder being called the secondary air. The leading types of burner systems may be divided into four classes, according to the duty of the carrying air:

1. All mechanical air from a single source. Fuel mixed with air at a distance from furnace front.
 Unit system.
 Stroud system.
 Grindle system.
2. Low-pressure distribution in suspension. Carrying air, 20 to 40 per cent. of total.
 Holbeck system.
 Heyl and Patterson system.
 Kennedy-Van Saun system.
3. Fuel mixed with primary air from a mechanical source which performs local conveying duty from bin to furnace front. Secondary air is mechanical or induced.
 Rotary kilns.
 Quigley system.
 Lopulco system.
 Hanna system.
 Allis-Chalmers system.
 Arrowood system.
 Pruden carbureter.
 Pneumatic siphons.
 High-pressure burners.
4. Single air supply with fuel fed directly to burner. Fuel falls vertically from feed screw to burner without carrying air, or is mixed with induced air supply.
 (*a*) All mechanical air.
 Bergmann system.
 Garred-Cavers system.
 (*b*) Induction burners.
 Fuller-Lehigh system.
 Warford system.

1. *Single Air Supply; Fuel Mixed at a Distance from Burner.* *The Aero pulverizer* is installed a few feet away from the furnace front and operates on the unit system (Fig. 105).

The Stroud System employs a "powdered coal stoker" consisting of a feed screw mounted above a fan blower. The

screw delivers the coal through a fall pipe to the suction side of the blower and it is mixed with the air in passing through the fan.

The *Grindle system*, as applied to the firing of a malleable-iron melting furnace, is shown in Fig. 111. A variable-speed motor drives both the feed screw and the blower which furnishes all the air. The coal is discharged against an equalizer plate mounted on the end of the screw which smoothes out any pulsations in the rate of fuel feed due to any packing of the coal along the screw. The conveying pipe may range in length from 3 to 100 ft. and ends in an enlargement known as the carbureter. This contains a mixing device consisting of a circle of stationary vanes, within which is a second set of vanes which is kept in rotation by the passing air. On high-temperature furnaces, where it is necessary to control the direction and length of the flame, the carbureter ends in a water-cooled nozzle, within which is a deflector plate, also water-cooled, which can be tilted downward to depress the angle of the flame. The Grindle system is made by the Combustion Economy Corp., of Chicago.

2. *Low Pressure Distribution in Suspension.*—This has been fully reviewed under conveying.

3. *Fuel Carried Locally by Primary Air.*—The fuel is mixed with mechanical primary air at individual furnace bins and is carried to burners, where it mixes with secondary air for combustion.

Rotary kiln practice usually follows this principle, about 25 per cent of the air for combustion being supplied by blowers at pressures of from 5 to 7 oz. Individual blowers are often used for each kiln, but in some plants the blower installation is centralized. The coal bins are located across the firing aisle from the kilns and the coal is dropped into the blast pipe by a feed screw whose speed is controlled by means of a Reeves variable speed mechanism.

The secondary air is usually induced by the stack draft, most of it being drawn in through the clinker discharge opening from the cooler or clinker pit below. This air is preheated in its passage through the latter. Air is also drawn in between the hood and the revolving shell, but very little air enters through the ports around the blast pipe.

The Quigley burner system is shown in Fig. 140. The feed screw on the left takes the coal from the bottom of the hopper (*A* 94) and drops it into the primary air line (*A* 34) in front of a

nozzle. The primary air is supplied by a fan blower at a sufficient pressure to carry the coal to the burner—about 6 oz., depending on the length of the pipe and its slope, and represents about one-eighth of the air required for combustion. The jet creates a slight vacuum about the screw which prevents the bridging or arching of fuel in the bin.

The secondary air is supplied by a low-pressure blower and enters the burner pipe through the annular space around the primary air pipe. Then it enters the furnace with a low velocity, as mentioned on page 517. The expansion of the primary air by heat in the furnace causes the fuel to mix with the surrounding annulus of combustion air. The length of the flame can be

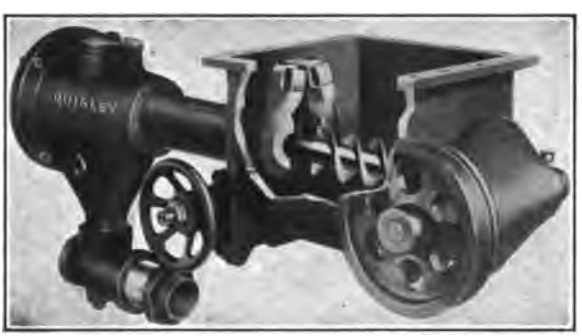


FIG. 141.—The Renkin controller.

varied by changing the position of the tip of the primary air pipe with respect to the larger pipe which forms the burner proper. Advancing the tip causes the mixing to occur later and gives a longer flame.

The Renkin controller, used with this burner, is shown in Fig. 141. Its distinctive feature is that the screw is operated at constant speed while the fuel supply is varied by means of a pair of shutters which may be closed around the shaft, a gap being left in the worm for this purpose. The shutters prevent the flushing of the coal, which is a frequent trouble with some types of feed screws. The controller shutters are operated from the floor by means of chains, or a handwheel, and a delicate adjustment of the fuel supply may be made. The secondary air supply is controlled by a blast gate (*A* 38), while the primary air supply is left constant to maintain the velocity of the air and keep the coal in suspension. The fuel supply may be entirely

shut off by a gate, as shown in Fig. 142, which is located just above the controller. It is of heavy construction and is dust-tight. *It is also used for regulating the fuel passing to the controller.*

The burners range in diameter from 8 to 14 in. The controllers range in capacity from 125 to 1,250 lb. per hour. This system is made by the Quigley Furnace Specialties Co., of New York.

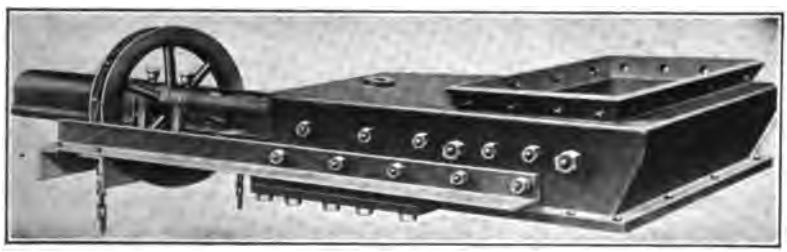


FIG. 142.—Gate valve.

The Lopulco Burner System.—The burner supplied by the Pulverized Fuel Equipment Co. for industrial furnaces operates with forced draught, similarly to the system described above, while the burner used for boiler firing operates with induced draught (see Fig. 143). In the latter case the primary air forms only an extremely small percentage of the total air and the pipe enters the burner vertically, which admits of the use of low velocity in carrying the coal. The furnace vacuum sometimes

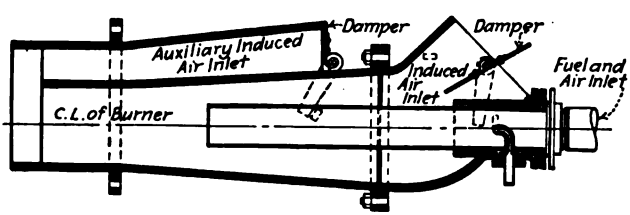


FIG. 143.—Lopulco burner.

extends back into the primary air pipe, while part of the secondary air is admitted through a cellular casting which surrounds the coal pipe and is fitted with dampers. The remainder of the secondary air is admitted through dampers in the front wall of the furnace, as described in another place. The controller is designed to prevent the coal from arching in the bin, the portion of the screw buried in the coal being quite long, and the primary

air is allowed to leak back into the coal and aerate it to keep it feeding uniformly. The screw is made with a shallow rounded groove to prevent "flushing;" *i.e.*, the tendency of the coal to slide through the spiral at a speed in excess of the rotation of the screw. A paddle wheel is mounted on the discharge end of the screw, which agitates the stream of coal and breaks up any lumps of adhering particles. These features tend to secure uniformity in the rate of feed to the burner. The controller is built in capacities ranging from 900 to 3,000 lb. of coal per hour.

The Hanna anthracite burner for boilers employs primary air largely for the purpose of carrying the coal into the furnace in the form of a broad flat stream which may be rapidly heated and ignited by the radiant heat from the flame. The coal is discharged downward at an angle of about 20° with the vertical. This burner is described further on page 699.

The Allis-Chalmers coal feeder has either a single-feed screw or, for large capacities, two parallel screws mounted just above the tuyere pipe which converges in section to the mixing chamber. The screws discharge the coal through a small cylindrical screen, which assists in preventing any unevenness in the feed, and into the mixing chamber which is of cast iron and is designed to secure a uniform intermingling of the coal with the primary air. The latter is supplied by a blower, at low-pressure, and in many cases it may be drawn in a preheated state from regenerative brickwork, waste-heat air heaters, or, in the case of kilns, from the rotary coolers. Generally speaking, only 20 to 30 per cent of the air required for combustion is injected directly with the fuel in order to keep the velocity at the firing nozzle down. A plate steel pipe carries the intimately mixed coal and air from the mixing chamber to the nozzle.

The secondary air is either drawn into the combustion chamber by the stack draft, controlled by dampers, or is forced in by means of a blower. In most cases the air should be brought into the furnace through or around the fuel nozzle, to insure proper mixture with the atomized coal and to prevent deflection of the flame. It may, of course, be preheated. Various types of nozzles are supplied to suit the conditions.

The Arrowood multi-mix system includes, as its most prominent feature, a burner with a general assembly designed for an intensive mixing effect, working from within outward as to the mass of coal particles. The details are shown in Fig. 144, while Fig. 109

shows an exterior view of the primary and secondary mixing chambers on a burner installed on an air melting furnace for malleable iron.

The primary and secondary air are taken from a single blower and are delivered to primary and secondary mixing drums, both of which contain inner drums which are perforated with many small holes.

The feed screw delivers the coal to the inner drum of the "coal control," or preliminary mixing chamber, where it is met by a cross current of primary air. This consists of from one-quarter to one-eighth of the total air required for combustion, and is roughly mixed with the coal before passing through the perfora-

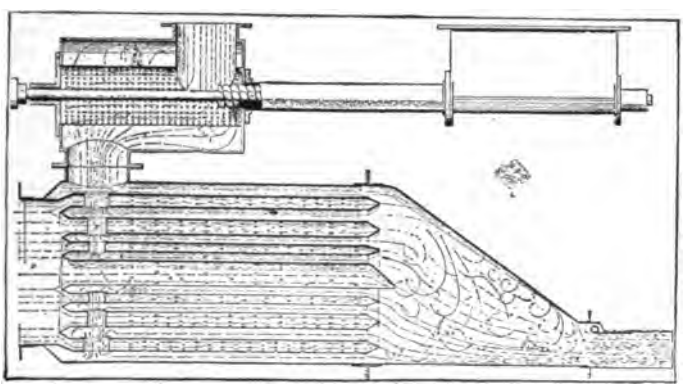


FIG. 144.—Diagram showing mixing action in pulverized-coal burner.

tions, of which there are about 560. In passing through these, the air expands to the lower pressure existing in the annular space between the inner and outer drums, and the coal and air are mixed by the numerous jets.

The secondary mixing chamber contains a number of perforated drums arranged concentrically. The intervening annular passages are closed alternately at the front and back. The primary air from the coal control is introduced through cross ducts to the rear ends of the annular spaces which open in front and is free to traverse the spaces and escape toward the burner. The secondary air enters the intervening annular spaces, and the central passage, which open toward the rear. Being under a higher pressure than the expanded primary air, it issues from the numerous perforations in small jets at right angles with the stream

of primary air carrying the coal. This effects a thorough mixing of the two streams and the coal is evenly diffused through the air before entering the furnace. With ordinary fan blast the jets will pierce little more than 2 in.; hence the stratification of the secondary air facilitates positive diffusion of the coal.

The burner on the malleable iron melting furnace at Erie, Pa. (page 533) has a triplex secondary mixer, 22 in. in diameter and about 9 ft. long. This contains five concentric inner drums perforated with 796 small holes. Together with the outer shell, these form three annular mixing chambers. The fan blast is usually supplied at a pressure of from 1 to 1.5 in. of water and enters the mixers through a 14-in. valve. With 1 oz. air pressure this burner is capable of handling about 2,000 lb. of coal per hour.

The mixer ends in a rectangular burner nozzle, 5-in. high by 40 in. wide. When the furnace is cold, there is a visible dark triangle of igniting coal, 2 or 3 ft. long, issuing from the burner, but this practically disappears when the furnace becomes hot and the flame then extends back to the nozzle.

Smaller burners for the average malleable iron annealing oven have two sets of mixing shells, from 6 to 10 in. in diameter and 3 or 4 ft. long overall. With these burners the ignition is so prompt that the flame extends back to the nozzle even when the furnace is cold.

A larger burner, with a secondary mixing drum 30 in. in diameter, is being used for firing a large rotary kiln at Maple Grove, Ohio. This burner is operated with air under a pressure of about one inch and feeds from 3,000 to 3,500 lb. of coal per hour.

While this system requires a large external mixing apparatus, it is claimed that the thorough mixing of the fuel and air before admission to the furnace effects a substantial saving in the furnace volume required for the complete combustion of the fuel which more than offsets the space occupied. Also, that the combustion conditions in the furnace are improved and troubles with the slag or ash are reduced to a minimum. It is claimed that high furnace temperatures may be obtained without the necessity for protecting the brickwork with blankets of cool air. This burner is built by the Ground Coal Engineering Co., of Chicago.*

*References: "Efficient Use of Pulverized Coal in Malleable Foundry Practice," by MILTON W. ARROWOOD. Presented at the annual meeting of the American Foundrymen's Association, Philadelphia, Sept. 29–Oct. 3, 1919. *Iron Age*, Jan. 22, 1920, 259.

The Pruden carbureter system is shown in Fig. 145. Primary and secondary air are supplied from a single source under a pressure of from 3 to 5 oz., and are tapped from the air main through the two pipes (5). The feed screw (3) draws the coal from the bottom of the furnace bin (1) and delivers it to the inner drum (4) of the preliminary mixing chamber. The primary air enters the annular space between the inner and outer drums of this mixer and then passes through a large number of perforations in the inner shell. It expands through these orifices in a multitude of jets and is evenly distributed throughout the mass of coal,

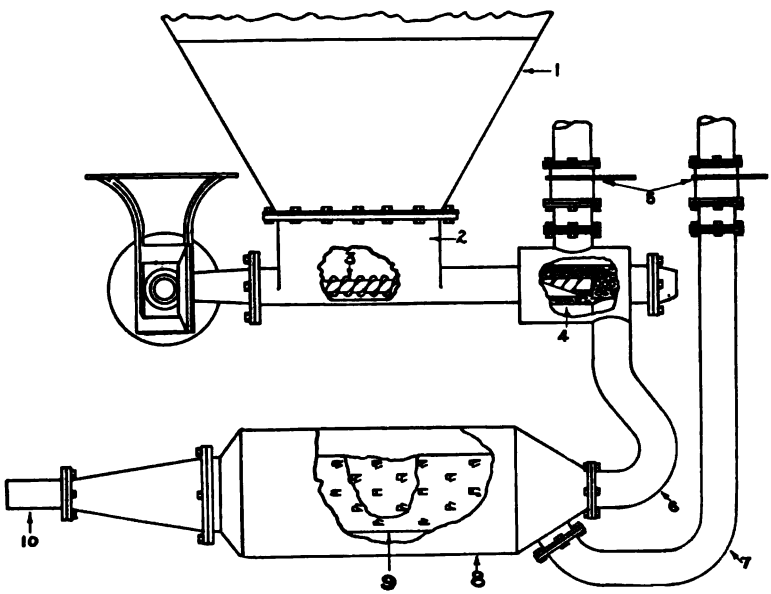


FIG. 145.—Pruden powdered coal carbureter unit.

which is then carried in suspension, through the pipe (6), to the inner drum (9) of the carbureter. The secondary air enters the outer shell (8) of the carbureter at line pressure, from pipe (7), while the primary air has been reduced to a lower pressure during its expansion in passing through the orifices in the preliminary mixer. The secondary air, therefore, enters the inner shell (9) of the carbureter through a multitude of small orifices and becomes thoroughly mixed with the coal, in the proper proportion for combustion.

The air and coal enter the furnace through the carbureter nozzle (10) under a static pressure which does not exceed one-

tenth of an inch and are very thoroughly mixed. Consequently the flame is soft; there is no blow torch effect; the flame starts at the top of the burner and the combustion is extremely rapid. The length of the flame is dependent upon the proportion of air used, an oxidizing flame being short while a reducing flame is long. The latter is sometimes used in reverberatory furnaces where a reducing condition is required.

The control is effected by two levers, one of which varies the speed of the feed screw, and consequently the rate of fuel supply, while the other varies the opening of the blast gate in the secondary air pipe. The screws feeding coal to the several burners on a single furnace are belt driven from a countershaft. This, in turn, is driven by a constant speed motor through a Reeves variable speed pulley. This system is made by the Powdered Coal Engineering and Equipment Co., of Chicago.

Pneumatic siphon fuel controllers have been used by several companies as a substitute for feed screws. They operate as ejectors, the suction pipe, being inserted in the side of a coal bin near the bottom, draws the coal out and feeds it into the primary air line.

These controllers have been used for a number of years and one of the first companies to use them in regular operating service, on a considerable scale, was the Eastern Steel Co., of Pottsville, Pa. At this plant they were first used in connection with high-pressure burners for firing open hearth steel furnaces, the operating air being at 40- to 80-lb. pressure (see Figs. 146 and 147).* This company has since applied them to low-pressure burners on heating furnaces as well.

Another design of pneumatic siphon controller is shown in Figs. 148 and 149. This was developed by the American Locomotive Co., at Schenectady and is being used very successfully on small forging furnaces, as shown in Fig. 109. The operating air is throttled to about 15 lb. pressure and less, the fuel supply being controlled by varying this pressure in unison with the throttling of the fuel in the suction pipe. The two simultaneous throttling movements are synchronized by the links shown in the illustrations.

This controller has displaced an older type of feed screw formerly used at this plant. The suction gives a very positive

* From C. J. GADD: "Use of Powdered Coal in Metallurgical Processes," *J. Franklin Inst.*, September, **1916.**

and uniform fuel feed as it allows the air in the voids to expand and flake off particles of coal from the mass. This action avoids arching or breaks up the coal when packed. A small opening is sometimes made in the bottom of the bin to admit air which aids in freeing the coal. This controller is used on the boiler shown in Fig. 150, where it is operated with steam. The coal is generally fed downward to the burner, but the operating air may be supplemented with additional primary air for horizontal conveying.

Another type of pneumatic feeder is being used on heating furnaces at the works of the Bethlehem Steel Co. at Lebanon, Pa. The ejector is installed at the burner and the coal is drawn

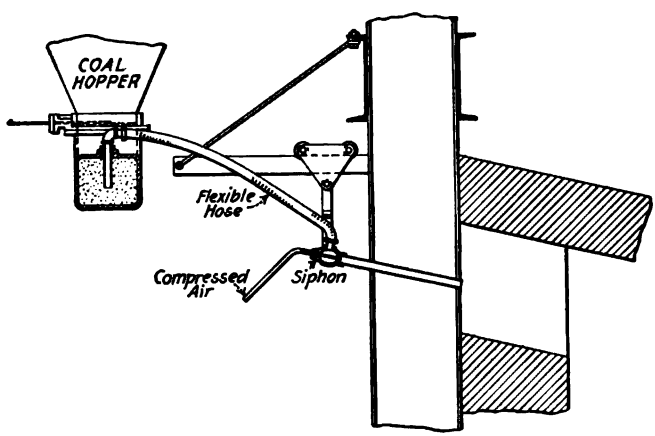


FIG. 146.—Pneumatic feeder for pulverized fuel; Eastern Steel Company.

from the bin by suction through a pipe which may be 8 or 10 ft. long.

High-pressure burners are used for firing open-hearth steel furnaces with a high-velocity blast, the secondary or volume air being supplied under a pressure of from 8 to 16 oz. The primary air is obtained from a compressed air main, under a pressure of about 100 lb., and is used for injecting the fuel into the tuyere. The coal is sometimes siphoned directly from the bin into the tuyere, as in Figs. 145 and 146. More frequently, however, it is drawn from the bin by a feed screw and then dropped to the suction side of the injector.

Low-pressure Pneumatic Feeder.—The pneumatic siphons mentioned above have the merit of simplicity, as compared with

mechanical feed screws, but the compression of the air requires considerable power. They are operated by air from the shop

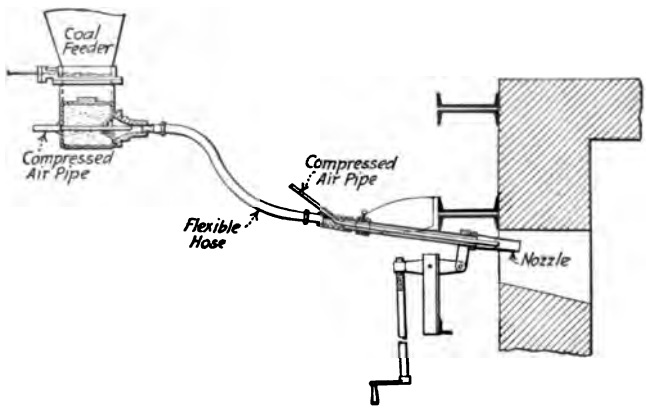


FIG. 147.—A sectional elevation of a mechanically operated high pressure feeding apparatus for powdered coal.

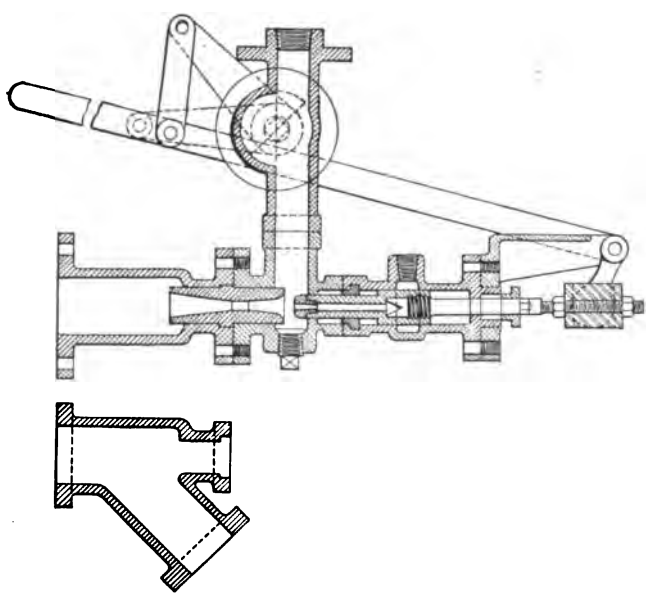


FIG. 148.—Pneumatic feeder for pulverized fuel; American Locomotive Company.

lines, which is usually under a pressure of about 80 lbs. per. sq. in. This is often throttled to 15 lbs. or less. P. A. Leonard,

who designed and built the pneumatic siphons at the American Locomotive Co., in Schnectady, also found that coal could be drawn from the bin when working with air at 1 or 2 lbs. pressure, although the ejector was not proportioned for efficient operation at such low pressures.

At the suggestion of the author, some experiments were made by the Thompson Laboratory of the General Electric Co., at



FIG. 149.—Pneumatic siphon controller used by the American Locomotive Company.

at Lynn, Mass., with a view to developing an ejector for operation with air furnished by the centrifugal compressors which are built at this plant. The ejector, which is of a special design, was built under the direction of S. A. Moss, of the Mechanical Research Department, and is based on the experience gained in working with air at relatively low pressures, and with ejectors for other purposes. It is installed inside the L-shaped casting

which forms the foot of the coal bin. The apparatus was set up merely for preliminary experimenting in conveying.

The compressor was driven by a 3 hp. direct-connected induction motor at 3,450 r.p.m. It is a 3-stage machine, with a capacity of 350 cu. ft. of free air per minute and a pressure of 45 inches of water (1.63 lbs. per square inch) was maintained at the ejector. The air passes vertically downward through the ejector and then into the feed pipe. Just above the ejector is a three-way valve and a by-pass which can deliver additional air to the feed pipe if it is required for conveying coal to the burner. The feed pipe passes through two elbows and then rises vertically,

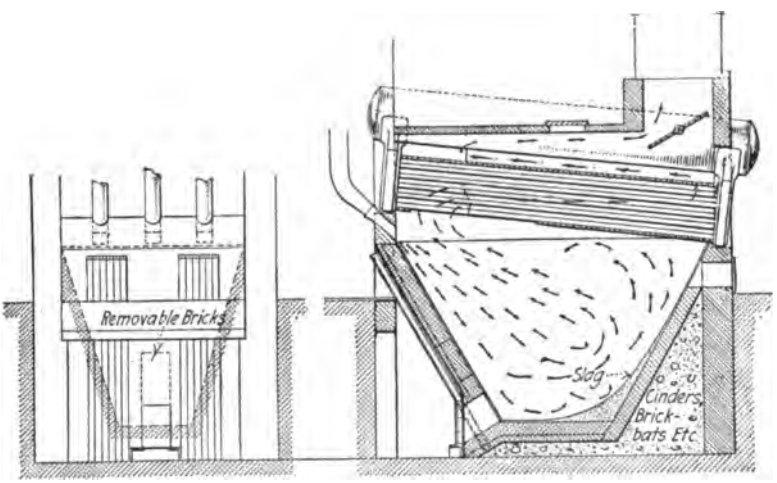


FIG. 150.—Experimental hopper shaped boiler furnace. (*From "Use of Powdered Coal as a Fuel," by C. L. Heisler, Mech. Eng., Dec.*, 1916.)

about 15 feet, and finally discharges the coal out of doors, so that the regularity of the flow may be observed, in the absence of a furnace and burner. A valve was placed in the vertical pipe, in order that additional back pressure might be provided during some of the tests. The capacity of this apparatus has been roughly determined as about 1,000 lbs. of coal per hour and the flow appears to be uniform.

This type of feeder may be applied to the present types of burners which are designed for operation with primary and secondary air from separate sources. The centrifugal compressor will supply the primary air, while the secondary air will be obtained from low-pressure blowers. The elimination of feed

screws will make it possible to centralize the motive power for operating the burners for a battery of boilers, or furnaces, and to locate the equipment in a place where coal dust will not sift into the motors. A battery of furnaces would be served by a single compressor of suitable capacity. The furnaces will then be free from mechanical apparatus and the installation may be as simple as when burning gas or oil.

4. Single Air Supply; Fuel Fed Directly to Burner.—(*A*) *All Mechanical Air.*—In one cement mill, visited by the author, the fuel was conveyed from individual bins, across the firing aisle to the kilns, by a long feed screw made from a section of standard

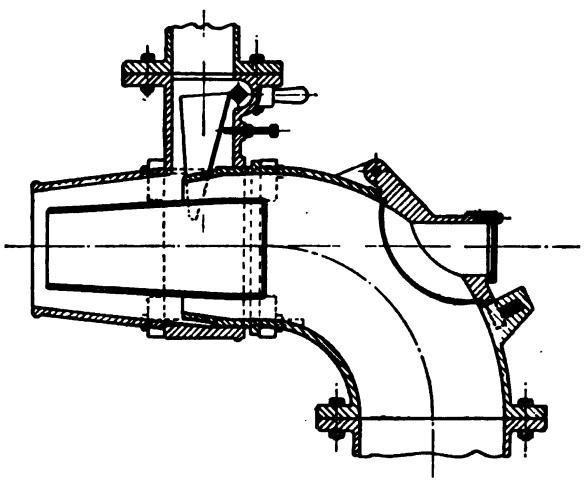


FIG. 151.—Type A pulverised fuel burner of the American Industrial Engineering Company, Chicago, Ill.

conveyor. This screw dropped the coal directly into the tuyere pipe which carried the air from a distant blower. While this was an improvised equipment, yet it will serve by contrast to distinguish the systems to be described under this heading from those previously reviewed, where the coal is conveyed to the burners by air. The feed screws are usually made fairly long and with a fine pitch to avoid flushing of the fuel, but are not generally used for actual conveying duty, as in the case just cited.

The Bergmann system uses a relatively long feed screw, in some instances as long as 25 ft., according to the location of the bin with respect to the furnace. The fuel is dropped through a

vertical pipe to the burner, one form of which is shown in section in Fig. 151. The fuel is deflected by the adjustable scoop at the foot of the fall pipe and is distributed around the inner cone. The air from a common source is divided into two streams by the inner tube, the outer stream picking up the fuel and carrying it into the furnace in the form of an annulus of coal and carrying air, surrounding a core of combustion air. The expansion of the latter by heat causes it to mix thoroughly with the fuel in the furnace.

The air leaves the burner tip under a combined pressure and velocity head of from ½ to 1 in. of water. The combustion commences within 1 or 2 in. of the tip and the velocity is low enough for most of the slag to settle in the combustion chamber, leaving a clean flame to go into the furnace. As much as 75 per cent of the ash is deposited in the combustion chamber.

By adjusting the angle of the scoop, the coal may be uniformly distributed around the inner cone, or a thicker mixture may be had on the top or bottom. In the back of the burner is a peep-hole with a glass window for observing the flame. By pushing the glass aside, a flat strip of steel can be run through for cleaning the burner while it is in operation.

One of the incidental points claimed for this system is the fact that the feed screw in the bin operates under neutral pressure; therefore, the rate of feed is not affected by the level of the fuel and the entire contents of the bin may be withdrawn. In systems where there is a positive or negative pressure in the bottom of the bin a certain static head of fuel must always be left to secure proper feeding. The front conveyor casting is provided with an atmospheric vent which, incidentally, indicates any stoppage of coal. This equipment is made by the American Industrial Engineering Co., of Chicago.

The Garred-Cavers high-pressure burner has been described under copper blast furnaces.

(*B*) *Induction Burners.—The Fuller induction-type burner* is presented in Fig. 152 and complete burner systems, including the bin and fall pipe, are illustrated in Figs. 167 and 168, in which they are installed for firing boilers. This burner consists essentially of two tubes, one inside of the other. The inner tube is provided with a vertical opening and a horizontal opening. The vertical opening is connected to the pulverized coal feeder. The horizontal opening is connected to the pressure air supply. A

blast gate is provided in connection with the inner tube for controlling the amount of pressure air entering the burner. A deflector plate is placed directly under the vertical coal inlet of the burner and this insures a thorough admixture of the pulverized coal with the pressure air, which acts as a carrying medium to project the fuel into the furnace.

The outer tube is fitted with an adjustable register, through which the secondary air is induced from the atmosphere by the action of the jet of primary air issuing from the end of the inner tube, the latter ending some distance back from the burner tip which is formed by the outer tube. The primary air is supplied by a blower under a pressure of about 2½ oz. and represents from 50 to 60 per cent of the air required for combustion. This burner is suitable for various types of furnaces where low velocity firing is required, as mentioned on page 517, including rotary kilns. With suitable modifications it can be arranged for using preheated air. One type of feed screw is shown in Fig. 153. It is driven by a chain and sprocket from a variable speed motor.



FIG. 152.—Fuller Lehigh burner, induction type.

The Anaconda Copper Mining Co. uses an induction-burner system of interest at the Washoe smelter (page 544). As there was no space available for the installation of individual



FIG. 153.—Fuller Lehigh feed screw.

blowers at each furnace, the blower plant was concentrated, the equipment consisting of seven centrifugal air compressors, each unit delivering 10,000 cu. ft. of air per minute at a pressure of 1 lb. per square inch. This primary air is distributed through a single main to the furnaces, where the excess pressure is utilized for inducing secondary air. The primary air represents from 45 to 50 per cent of the air required for combustion, and the blower plant and

piping are, therefore, considerably smaller than would be necessary for the distribution of 100 per cent mechanical air.

The balance of the air is induced through various ports arranged to obtain a thorough mixing of the fuel and air, part of the air being induced near the end of the feed screw to carry the coal to the burner. The air leaves the burner under a pressure head of between 0.5 and 1.0 in. of water. The power consumption is only slightly in excess of what would be required by using all mechanical air from low-pressure blowers. The greater reliability of the centrifugal compressors was the determining factor in the choice of equipment, as this plant must operate continuously and burns a large amount of fuel. The installation was designed by N. L. Warford and the compressor sets were furnished by the General Electric Co.

The Storage System with Bins at Furnaces.

It will be noted that most of the commercial systems follow this general practice. The arguments in its favor are:

1. Individual storage bins at the furnaces render the continuity of the fuel supply independent of temporary shut downs of the milling plant or conveying system.

2. A single conveying system can transfer fuel from the milling plant to the furnace bins.

3. The fuel can be more readily conveyed in pulverized form than as raw fuel.

The disadvantages claimed by the advocates of other systems are:

4. The location of the storage bins in proximity to the furnaces subjects them to heat which sometimes causes spontaneous ignition of the fuel. This, it is claimed, may be avoided by proper operating conditions which will insure that the fuel is cool and dry when it enters the bins, as discussed under *drying*.

5. The use of individual bins and feed screws on a large number of small furnaces renders the installation expensive. The development of the pneumatic siphon type of feeder should simplify the equipment and render possible the feeding of several small furnaces from a single bin.

Availability of Equipment.—Many of the earlier installations were equipped and developed by the factory engineering organizations, to a large extent. A number of engineering firms are now making a specialty of the designing and equipment of pulverized fuel installations. The equipment which is available today has

been developed and standardized as the result of several years experience and, while the art is still rapidly advancing, the greatest number of problems remaining to be solved relate to various special applications for pulverized fuel. There is still room for simplification of some of the equipment and for improvement in furnace design, and a few of the lines in which advances are being made have been indicated.

THE FIRING OF BOILERS WITH FINELY DIVIDED FUELS

The general advantages of utilizing fuels in fluid or semi-fluid form, for the generation of steam, have been reviewed on pages 317, 318 and 319. The choice of fuels for use in most industrial processes, in pulverized form, is limited to relatively high-grades of bituminous coal or lignite and direct heating is a high use for fuel. The generation of steam is an indirect application of heat for which a wide range of fuels may be utilized and, therefore, should be considered a low use for fuel, as pointed out in Chap. V. A wider variety of methods for firing boilers with powdered fuels is practicable, than in the case of industrial furnaces.

Granulated Fuel.—From this viewpoint, the possibility of using powdered fuel dates back as far as 1818, when an engineer named Niepce experimented with the burning of coarsely pulverized coal over a grate fire. Various types of "throwing stokers" are used for feeding crushed coal to a grate fire by imitating the firing of coal by hand, but which eliminate the necessity for opening the furnace doors. The motive power may be either mechanical, pneumatic or steam, and the operation either intermittent or continuous. One European method consists in blowing finely divided coal onto a grate fire by means of steam.

Marine Boilers.*—Mechanically operated throwing stokers are used on locomotives and the limitations encountered in applying mechanical stokers or pulverized coal on shipboard have attracted attention to the possibilities of firing marine boilers with pneumatic stokers and granulated coal. The preparation of granulated coal for this purpose has been discussed on pages 557 and 558.

Some experiments were made in 1918 by A. M. Hunt, of the Ship Protection Committee, of the United States Shipping

Board, on a small freight steamer running between New York and New London, Conn. This boat had two Scotch boilers, one of which was equipped for pneumatic firing, the other being fired by hand. The only change made in the boiler was to introduce a small pipe into the furnace front above the firing door.

A small hammer mill was installed over one of the bunkers and reduced the coal to ⅜-in. and finer sizes, ranging to dust, while coaling ship. Pocahontas coal was used which is of semi-bituminous rank. The coal was shovelled from the bunker to a temporary bin, from which it was drawn by a pneumatic siphon feeder operated by air furnished by a small positive-pressure blower under 3- or 4-lb. pressure. The coal was carried in suspension by primary air, which represented only a small fraction of the air required for combustion, and was continuously sprayed over the fire from the pipe which ended in a flattened nozzle. The combustion air was admitted partly below and partly above the grate in the usual way.

A fire was first built on the grate with lump coal. Then the "pneumatic stoker" was started and the dust content of the granulated coal burned in suspension, while the coarse particles settled on the fire bed after being semi-coked by the radiant heat. This resulted in maintaining a free-burning fire which formed practically no clinker, while heavy clinkers had to be removed when the fire was cleaned in the hand-fired boiler. Only a little hand trimming was required as the flattened nozzle gave a good lateral distribution, while the variation in the sizes of the particles gave a good distribution fore and aft. The ash was powdery and dropped between the grate bars freely.

The portion of the fuel which burned in suspension included both the dust and the volatile matter of the coarser particles. The furnace efficiency was found to be considerably higher than with hand firing, and the flexibility and responsiveness of the fire were comparable with oil firing. Steam could be raised rapidly to meet sudden calls for power. The pneumatic siphon feed required attention on the part of the fireman, owing to the variations in fineness and moisture content of the fuel, which caused it to feed at ununiform rates. With a fuel of variable quality the more positive feed screw would be preferable. This method is also in successful use on a Niclausse marine water-tube boiler at the Naval Experiment Station, at Annapolis, Md., where Hunt made his initial experiments.

In some types of marine boilers, including the Scotch boiler and possibly the A-type water-tube boiler, such as are used on many naval vessels, the firing of granulated fuel over a grate has an advantage over pulverized fuel in that no more refractories are required in the furnace than when coal is fired by hand. Ignition is effected by radiation from the fire in spite of the large area of heat absorbing surface above the fire. The latter, at the same time, absorbs enough radiant heat from the flame to keep its temperature below the melting point of the ash. The small semi-coked lumps then drop on the fuel bed and make a free burning fire through which the underfire air can readily pass to complete the combustion. The character of the fire evidently bears a striking resemblance to the burning of semi-coke prepared by low temperature distillation (see pages 468 and 469 and 500 to 503).

The availability of the furnace for reversion to hand firing is an important consideration on board ship, as it renders the operation of the vessel independent of the availability of particular fuels. Coal may be taken aboard at regular coaling stations and carried in the bunkers in lump form. It may then be granulated and fired on either the unit system or the storage system. If it is necessary to stop the mill for repairs, lump coal may be fired by hand temporarily. To obtain the full advantages of preliminary preparation, the fuel should be dried and granulated on shore. Then vessels operating on regular routes could be coaled from barges by pneumatic methods (pages 637 to 647) and similar methods could be used for conveying from bunkers to furnaces on the ship. Reversion to hand firing would be possible whenever a supply of prepared fuel was unavailable.

The range of available fuels may be considerably increased if it should be practicable to burn lower grades of coal in granulated form than by hand firing.

Stationary Boilers.—Granulated fuel should be especially applicable in small plants where it would be expensive to pulverize coal on a small scale. Semi-coke could be granulated at coal-distillation plants and distributed to small consumers in tank cars, or tank trucks. Granulated coal could be similarly distributed. In building heating plants it would have the following practical advantages over oil and pulverized fuel:

1. The grate fire renders it less dependent upon the con-

tinuity of operation of the electrical and pneumatic firing equipment. This leaves the fireman free to attend to other duties.

2. Most of the ash remains in the furnace, only a small amount going up the chimney.

3. No disagreeable odor or dust when starting a fire in a cold furnace.

4. Few changes need be made in the furnace.

5. As compared with hand firing, the elimination of smoke and the reduction in labor.

In large boiler plants the only advantages of granulated fuel over pulverized fuel are the lower cost of preparation and item (2) above. The simplicity of the preparation, however, may be offset by the limitations of the large hammer mill. This is a dusty machine to operate and must be taken apart frequently to replace worn hammers. In small hammer mills, however, the working parts are more accessible and it should be easier to keep them dust tight.

If the fuel is passed through a roll crusher and then dried, it could be granulated in a short ball mill and would then be in suitable form for convenient handling and conveying, as well as for safe storage. To what extent the drying operation could be reduced, in cases where it is less necessary, would be a matter of interest.

The lesser amount of ash sent up the chimney may be an advantage in some localities. When burning high-ash coal in pulverized form in building heating plants, it has been found that dust collectors would be desirable.

Granulated fuel lacks one of the important advantages of pulverized fuel, in that the grate fire must be kept burning slowly during banking periods, while fuel burning in suspension may be shut off entirely.

Burning Coarse Fuel in Suspension.—A number of patents have been taken out, and experiments tried, on methods for burning granulated fuel in suspension in air. Up to the present time, however, no practical system has been developed.

It would seem that the only advantage to be gained, over the method just described, is to obtain a fire which may be shut off for banking. This assumption, however, is based on the claim that no unburned combustible matter was carried into the rear passes, or up the stack, in Hunt's experiments. When burning coarsely pulverized coal in suspension, the loss from combustible

matter carried beyond the fire has sometimes been quite appreciable and it would appear to be much more difficult to prevent than when firing granulated coal over a grate. In the latter case, the velocity of the air may be very low in the combustion zone, as all coarse particles are to be dropped on the fire.

As regards the maximum size of powdered fuel which it is practicable to burn in suspension, E. R. Wells and W. H. Jacobi make the following statement:*

"Experience shows that under favorable conditions 100 per cent 60-mesh powder can be burned satisfactorily. This coarse fuel necessarily requires a longer time for its complete combustion and it can only be carried in suspension at high velocities. Its use, therefore, would be permissible only in furnaces which provide a long path for the resulting flame. In short chambers operating at low velocities these large particles fall to the bottom of the chamber and coke before being consumed, the result being a loss of fuel. Pulverized coal larger than 80-mesh grade should be avoided in ordinary operation for the best results."

Some authorities are skeptical as to this statement; there being no practical way of securing such uniformity in the size of the coal. Air separation mills give the nearest approach to a uniform product, but there is bound to be a considerable proportion of finer material present which will aid combustion. It is claimed that the above experience must be based on an erroneous assumption that the material was of uniform size. The screen type Fuller mill, when grinding to a fineness of 85 per cent through a 200-mesh, will produce a product all of which will just about pass through a 50-mesh screen.

Anthracite.—The burning of low volatile fuels, like anthracite and coke breeze, is a special problem which is quite distinct from the burning of high volatile fuels. The steam sizes of anthracite are largely burned in small boiler plants in manufacturing establishments and for heating buildings in cities where the smoke from soft coal is objectionable. Coke breeze is burned largely in the gas and coke-oven plants and steel mills where it is produced. Most of the firing is done by hand, but certain types of stokers are coming into fairly extensive use. As mentioned on page 277, the most successful automatic stoker for these fuels is of the traveling grate type. Certain types of overfeed stokers are also used, including both automatic types and "hand stokers." In

* "Pulverized Coal as a Fuel for Boilers," *Mech. Eng.*, September, 1919.

the case of the latter, it is necessary to mix about 25 per cent of bituminous slack with fine anthracite to cause a caking action to take place.

The traveling grate operates most efficiently on the larger steam sizes of anthracite, No. 1, No. 2 and No. 3 buckwheat, of which only No. 3 buckwheat is ordinarily available at a sufficiently low price for extensive use in plants where stoker firing is used. The first essential in burning small anthracite is uniformity in the size of the coal. It is extremely difficult to get satisfactory efficiency with a mixture of No. 2, No. 3 and No. 4 buckwheat because the various sizes segregate on different parts of the grate. This results in a lack of uniformity in draft resistance through the grate and fuel bed; but where there is a preponderance of the coarser coal the resistance is less and the fines will be blown off the grate. It will be practically impossible to burn the coal at this spot and it will pass through the furnace without even becoming red hot. This condition may be accentuated when there is a lack of uniformity in the air spaces in the grate. The normal clearance between the ends of the keys is $\frac{1}{16}$ inch, and it is important that a reasonable uniformity be maintained in the large numbers of these small spaces. When worn or broken parts are not replaced, the clearance between some of the keys may become as high as $\frac{1}{4}$ inch.

No. 3 buckwheat is the most satisfactory fuel for the Coxe stoker and it is the size of which the largest tonnage is so burned. Commercial No. 3 buckwheat contains anywhere from 15 to 20 per cent of wet which will pass through a $\frac{3}{32}$ in. screen, and of this percentage a certain variable proportion will pass through a $\frac{3}{64}$ in. screen. It is probable that the greater portion of the extremely fine size is lost in the ashpit and up the setting, and the efficiency therefore depends to a greater extent on the percentage of under size.

The forced draft grate stoker, as represented by the Coxe stoker, will burn efficiently both No. 1 and No. 2 buckwheat, as well as No. 3, and with even better efficiency. The furnace design would be somewhat different from No. 1 and No. 2 buckwheat with No. 3. This stoker will also burn No. 4 buckwheat, but not with the same efficiency. At the same combustion rates the efficiency when burning No. 4 buckwheat will be about 10 to 15 per cent lower than with No. 3 buckwheat. This stoker will also burn silt or run-of-bank coal, provided there is not much

large coal in it. The efficiency will be still lower than with No. 4 buckwheat, probably between 40 per cent and 50 per cent at corresponding combustion rates.

A series of 10-hour tests were made in July, 1921, on a 242 hp. Wholey boiler equipped with a Mechanicville (or Smith) grate, in a plant at Bellefont, R. I.

The fuel used, in one test, was Rhode Island graphitic anthracite, from the Graphite Mines Corp., and of the following analysis:

Volatile matter	4.40 per cent
Fixed carbon	71.75 per cent
Ash	23.88 per cent
Sulphur	0.38 per cent

An overall efficiency of 67.5 per cent was obtained for the boiler, furnace and grate. The fires were cleaned one-half hr. or three-quarters of an hour before starting and stopping, and at noon. After cleaning fires it was found convenient, but not necessary, to use a little New River semibituminous coal. Another test was run in which 20 per cent of New River coal was mixed with Rhode Island coal. An efficiency of 70.5 per cent was attained, which was a sufficient gain to just offset the additional cost of the New River coal. In a third test, New River coal was burned alone, under a similar boiler, with an efficiency of 67.7 per cent. This test was made with rocking grates and natural draft.

It has been found that in order to burn anthracite at the highest possible rates it is necessary to burn the finer portion more or less in suspension. With No. 3 buckwheat on a hand fired grate of the proper design it is a comparatively simple matter to get rates of 25 lb. of coal per square foot or better. The attainment of such rates of combustion is accompanied by a high temperature within the fuel bed and unless the finer fuel is kept constantly in motion, so that the particles are separated until after they are completely burned out and cooled below the fusing temperature of the ash, large size clinkers are almost certain to be formed. Number 2 buckwheat can be burned in the same way, and with correspondingly higher combustion rates, but it requires exceptional uniformity in the air spaces of the grates and a high mean ashpit pressure. If the air spaces are not uniform, then the air will find an outlet along the path of least resistance, which, with a fuel bed of uniform thickness and composition, will be at the

point where the air space is the greatest per unit of area. At such a point in the fire the combustion will proceed at extremely high rates or the fuel may be blown completely off the grate. If the fuel is burned at very high rates at localized spots, high temperatures are produced and clinkers are formed around the spots while the rest of the grate suffers from a lack of air, the fixed carbon is not burned out of the refuse, and there is likely to be considerable CO formed.

With No. 4 buckwheat the clinker trouble is less, but when high rates are attempted the blast carries the fuel clear off the grate at the points where the clearance is excessive; and this fuel is very likely to find its way into the ashpit, for it is too heavy to be carried along in the gas stream. Sometimes the refuse from a No. 4 buckwheat fire contains as much as 50 per cent of carbon.

When we compare the fixed and travelling grates on the basis of width and length, it is evident that the fixed grate is under the disadvantage of accumulating the refuse between cleaning periods since it is not possible to shake or agitate an anthracite fire without mixing the fuel and ash. Consequently, shaking grates, such as are used for bituminous coal, cannot be used for burning fine anthracite in a thin fuel bed without loss of considerable carbon with the ash. Hence, fixed or dumping types of grates are used, and it is a common practice to mix a small proportion of bituminous coal with fine anthracite to obtain a caking action.

In the boiler plants at the mines no bituminous coal is mixed with the anthracite, owing to its much higher cost, but water is sometimes sprinkled on the coal to prevent loss of dust or fine coal. In some of these plants, where steam sizes are fired by hand under batteries of eight 250 hp. boilers, the efficiency attained is only 30 per cent without making any allowance for the fact that one of the boilers, equipped with a superheater, is used exclusively for furnishing the steam blast which induces the air for the forced draught for the other boilers.

At one mine silt is burned on travelling grate stokers with an overall efficiency of from 50 to 60 per cent, while the same type of stokers are burning No. 3 buckwheat in industrial plants with an overall efficiency of about 70 per cent. The boiler tests which have been made with pulverized anthracite (Table LXLIII) indicate that silt can be burned with a high efficiency

by this method. Where fine anthracite is burned on grates without the admixture of bituminous coal, the fact that it must be burned more or less in suspension, in order to attain high rates of combustion and yet maintain good efficiencies, entitles it to a place in the present Chapter.

When anthracite screenings or steam sizes are burned at points distant from the mines, and coal is expensive, the question of efficiency is naturally given closer attention. Special types of fixed or dumping grates have been designed for burning fine fuel. Some of the leading types may be classified as follows:

Grates with vertical air spaces.

1. Pin-hole grates.
2. Plain narrow slots.
3. Holes connected by slots (McClave grate).*

Grates with horizontal outlets to air spaces:

4. Pyramid grate.†
5. Mechanicville. ("J.R.S.") grate.‡

The first three types of grates have tapered air passages with the smallest section at the top in order to avoid stoppage. A draft of several inches of water is used in order to keep the fuel agitated, especially if burned without admixture of bituminous slack. These grates are often of the dumping type and some types are used for burning anthracite either with or without bituminous slack. The fourth and fifth types are used for burning fine anthracite alone, the horizontal slots at the tops of the air passages preventing the loss of fine coal through the grate.

The Pyramid grate is covered with small caps, about 2 in. square, having the form of a truncated pyramid. Each cap covers a circular air passage which branches at the top into four horizontal mouths. The air supply is thereby uniformly distributed over a thin fuel bed.

The Mechanicville grate is made of flat steel plates with longitudinal gaps, several inches in width, located at intervals of something over a foot apart. These gaps constitute the tuyeres and the air supply is piped to them from the blower under a pressure of from 10 to 20 in. of water, according to the load. The tops of the gaps are covered by cast-iron plates, about 8 in.

* McClave-Brooks Co., Scranton, Pa.

† Pyramid Iron Products Corpn., Yonkers, N. Y.

‡ Mechanicville Specialty Supply Mfg. Co., Mechanicville, N. Y.

wide, having downwardly flanged edges beneath which the air escapes. The ashpit is entirely sealed from the combustion chamber and is traversed by the air pipes. A large part of the pressure head of air is converted into velocity during the escape of the air through the horizontal slits, which are about $\frac{1}{8}$ in. wide. This fact renders the distribution of the air independent of the thickness of the fuel bed at different parts of the grate surface and avoids all tendency toward the blowing of holes in the fire. The two opposing jets from adjacent tuyeres keep the intervening fuel in constant agitation until consumed. The fire is usually cleaned by burning out each side alternately and then raking the ashes out onto the fireroom floor. Where steam-jet ash conveyors are used, the ducts may be piped directly to the grate plates.

The various types of grates and stokers, used for burning fine anthracite or coke breeze, have certain useful fields. The grates are suitable for small boiler plants and the stokers for a certain size of coal. Pulverized coal is more suitable for large boiler plants where it is not desirable to be limited to a single kind of coal owing to its limited availability. Where large quantities of coal are consumed, any available size of anthracite may be pulverized. A boiler furnace designed for burning pulverized anthracite may be used for burning pulverized bituminous coal when this is temporarily more available.

Anthracite is better adapted to storage in bulk for long periods since it is not subject to spontaneous ignition or deterioration due to oxidation or loss of volatile matter. If both fuels are used, the bituminous coal can be burned as delivered, the reserve storage being anthracite. These considerations apply equally well in the case of semi-coke from low-temperature distillation processes. Safe storage is especially important in connection with steam reserve stations operated in connection with hydro-electric transmission systems.

Amalgam of Coal and Oil.—Trent amalgam (page 629) made from bituminous coal has been burned experimentally in boiler furnaces on ordinary grates. In the open air it burns with a smoky flame, but with a good draft it burns with a clear flame and emits a shower of sparks, so that many of the coal particles are burned in suspension after they have been released from the amalgam by the distillation of the oil. No ash remains in the furnace, the mineral matter remaining in the clean coal being all

carried up the stack in the form of a light powder. The amalgam can be pumped through pipes and sprayed onto the fire bed when suitable devices are adapted to handling this viscous material. Its application as a fuel for ships and for small steam plants on land have been mentioned in Chap. V (pages 293 and 309).

PIONEER BOILERS FIRED WITH PULVERIZED COAL

A few comments have been made on page 518 regarding the history of the firing of boilers with powdered coal. The only type of boiler and furnace which has been extensively used, and which is at all adapted for coarser fuel than the standards mentioned on page 576, is the Bettington boiler. No claim is made regarding its ability to burn coarse fuel, as fine fuel was less available at the time of its development.

The Bettington Boiler.—This boiler was especially designed for firing with either powdered coal or with dust collected from mines and screening plants. The designer was Claude Bettington, of Johannesburg, South Africa, and several of these boilers were installed at the Rand mines. Others were installed in Great Britain and at Nova Scotian colleries. The fuels most frequently used were prepared from various forms of mine waste, usually high in ash.

The general type is shown in Fig. 154. The flame is projected vertically upward from a water-cooled tuyere, in the center of a cylindrical furnace surrounded by vertical water tubes. The inner circle of tubes are covered by special firebricks, except at the bottom, where the first pass is located. The flame assumes a mushroom shape, the velocity of the jet of air and fuel being sufficient to carry it nearly to the bottom of the steam drum at the top of the tubes. The gases then spread and return downwardly along the furnace walls until they pass outwardly and then upward between the tubes. The particles of fuel gradually lose their initial velocity in rising and then pass through the hot zone a second time in falling, thereby having time for the complete burning of the larger particles.

Some radiant heat is absorbed by the water-cooled surfaces at the top and bottom of the furnace, but most of the radiation falls on the firebrick lining and is reflected back, giving a very high temperature in the flame, which fuses the ash. The bricks are cooled, on their outer surfaces, by the tubes which protect

them from destruction by melting. They are set without fireclay and the gases short-circuit through the cracks until they are filled with a slag deposit. Molten slag is deposited on the walls and drips from the lower bricks into a cooler zone at the bottom, where it collects in solid globules, ¼ to ½ in. in diameter, which are readily removed every 24 hr. The face of the refractory lining would melt back, under heavy loads, until an equilib-

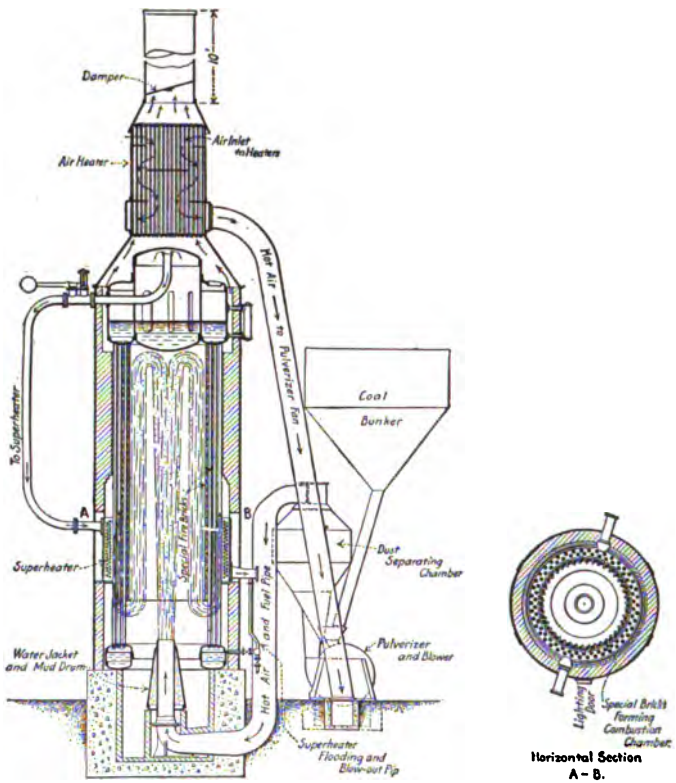


FIG. 154.—Bettington boiler. (*From Mechanical Engineering, Oct.*, 1914.)

rium was established with the rate of thermal conduction through the bricks. When operating at lighter loads, the slag deposit would build up the thickness of the lining until another condition of equilibrium was established.

Table LXXXVIII contains data from tests made with low-grade coals ranging in volatile content from 11.7 to 27.4 per cent.

Coals with higher volatile were also burned. The percentage of CO_2 in the flue gases averaged from 15 to 17 during regular operation.

TABLE LXXXVIII.—TESTS OF BETTINGTON BOILER

Country	Wales	England		South Africa		
Coal used	Anthracite, Duff	Clifton & Kersley	Nuts	Slack	Partings	Duff
Analysis, per cent (dry basis)						
Ash	12.6	23.0	22.2	17.9	22.6	20.0
Volume	11.7	20.0	26.0	23.4	27.4	23.0
F. C.	75.7	57.0	51.8	58.7	50.0	57.0
B.t.u.	12,276.0	10,700.0	8,710.0	11,109.0	10,098.0	11,088.0
Moisture, per cent (as fired)	0.8	15.6	8.7	2.2	1.6	2.4
Thermal efficiency	74.6	75.0	79.3	82.6	76.3	80.3
Average temperature of flue gases (degrees Fahrenheit)	560.0	593.0	514.0		558.0	604.0
Absolute steam pressure, pounds square inches	151.0	165.0	140.0	189.0	152.0	130.0

The fuel was pulverized in a paddle-type mill and fired on the unit system. In some of the earlier work the Aero pulverizer was used. As finally manufactured on a commercial scale, by Fraser and Chalmers, Ltd., of London, the Bettington pulverizer was furnished. This was a single-stage paddle mill, which also acted as a fan and furnished the draft. It was equipped with a cyclone separator for returning coarse particles. While no statement is made regarding fineness, the product from either of these mills was probably coarser than the product of modern ring-roll mills.

The coal was not dried before pulverizing and it will be noted that two of the tests were made with coal of high-moisture content. The air used for combustion was preheated in the tubular heater shown in Fig. 154, and then drawn through the pulverizer, which probably dried the coal during the grinding. With 12 lb. of air per pound of coal, the evaporation of 10 per cent of moisture would only cool the air about 17°C. (30°F.), in addition to which the heat generated in pulverizing should be sufficient to evaporate nearly 2 per cent of moisture.

Some authorities considered that the cost of maintenance of the refractories was excessive.

Erie City Iron Works Boiler.*—This boiler is of an experimental design prepared by the Aero Pulverizer Co. and equipped with their unit type of preparation plant. The furnace design includes some features of the Bettington boiler, in that the furnace is water-cooled by boiler tubes embedded in the walls. The furnace, however, is horizontal and is located beneath a boiler with horizontal tubes. The burner is located at one end. This boiler has been in operation during part of 1919 and 1920, and the results attained are claimed to be satisfactory. A high temperature is obtained in the furnace, which liquefies the ash and the resulting slag drains through a long narrow slit in the bottom of the combustion chamber. The boiler is rated at 402 hp. and has been operated continuously at 160 per cent rating.

This boiler has recently been tested in connection with a new design of pulverizer, designed by Frederick Seymour, of the Aero Pulverizer Co., who also designed the furnace. The new pulverizer is of the single-stage paddle mill type, having a long rotor to ensure fine grinding and reduce wear. An 8-hour test was run with Pittsburgh bituminous slack having a calorific value of 10,938 B.t.u. per lb. An efficiency of 81 per cent was attained for the boiler and furnace.

The Bettington type of boiler furnace represents the highest temperature conditions used in burning finely divided fuel, while Hunt's experiments with granulated coal probably represent the lowest temperature conditions in the furnace. Thus we have reviewed the two extremes and will conclude this historical review with a description of a successful boiler operating under intermediate temperature conditions.

American Locomotive Works Boiler.—Probably the most successful of the pioneer boilers, fired with pulverized coal, was a small boiler at the Schenectady Works of the American Locomotive Co. This was a 300 hp. Franklin boiler in the factory power plant and was one of a battery of similar boilers fired with Roney stokers. Pulverized coal is used for firing heating furnaces in the drop-forge shop and one boiler was changed to operate on fuel from the same milling plant in November, 1914. For the first trial only slight changes were made in the furnace. Trouble was encountered in the melting down of the furnace walls and arch, and in an inability to carry full load.

* Reference: "Pulverized Fuel—Why?" by E. R. KNOWLES, *Combustion*, September, 1920.

The furnace was rebuilt twice before satisfactory operation was secured, the final design being an improvised one made by C. L. Heisler and shown in Fig. 150. It was shaped like an inverted cone, but rectangular in plan, the necessary space being obtained by digging into the ground. The designer's idea was* that the best way to prevent the destruction of vertical walls and arches was not to have them, and to substitute incandescent surfaces formed by simple outwardly inclined walls which would be automatically maintained by a coating of protecting slag. This furnace was in continuous service, during factory working hours, from March, 1915, to September, 1919, when it was shut down owing to an interruption in the fuel supply; building operations necessitating a change in the location of the milling plant. The use of pulverized coal has since been extended to additional forging furnaces, which require the entire output of the present milling plant. During these four and one-half years the maintenance expense was negligible, no repairs being required on the hopper shaped furnace walls. These have been coated with a layer of slag, from 1 to 3 in. thick, which has absolutely protected them.

The coal was originally fed from the bin by feed screws. Later, pneumatic siphons were substituted and were operated with either steam or air. The tuyeres, where they passed through the furnace wall, consisted of 10-in. wrought-steel pipes.

The secondary air was supplied by a blower at a pressure of from 0.8 to 2.6 in. of water, according to the load, the pressure at the tip of the burner being considerably less, as it ranged from 0.2 to 0.3 in. in the tuyere before it entered the wall. The primary or carrying air fed the coal into the 10 in. pipes 4 or 5 ft. from the tips of the burners, and in a vertical section, above a 45° bend, which assisted in mixing the coal and air before ignition.

The coal and air were discharged downwardly into the hopper-shaped furnace and were thoroughly mixed and burned between the incandescent walls. The gases then rose and expanded into the broader space at the top of the furnace in a manner which gave the flames a slow rolling movement, as indicated by the arrows in Fig. 150, finally returning under the boiler to the first pass, over the burners. The flames thus traversed the full

* C. L. Heisler, "Use of Powdered Coal as a Fuel," *J. Am. Soc. Mech. Eng.*, Dec., 1916.

length of a 30-ft. path before coming in contact with heat absorbing surfaces.

No slag was carried up among the tubes, as all ash remaining in the gas was carried through the tubes and up the stack as dust. Only occasional blowing was required to dislodge ash dust from the tubes or baffles, no more cleaning being required than in the case of the stoker-fired boilers in the plant. About one wheelbarrow-full of ashes was removed at the end of each day's run. This was taken from the door in the front of the furnace, below the burners. This door, and the bottom of the furnace, were somewhat cooled by air leakage, and the slag which fell from the fire collected therein as flat clinker-like lumps which were readily removed with a hoe. The ash was practically free from carbon.

There was a very slight inward suction through the ash door while the pressure at the top of the furnace was atmospheric. In the gas passes there was a slight vacuum from the stack draft.

A CO_2 recorder showed an average CO_2 content of 15.5 or 16 per cent in the gases. Readings as high as 18 per cent have been recorded; this indicates complete combustion without excess air. The coal used contained about 30 per cent volatile matter and about 10 per cent of ash.

The control of the air and fuel was simple and required but little attention. The boiler has been operated by the regular firemen of various nationalities. They much preferred the pulverized coal fired boiler to the stoker-fired boilers.

Much credit for the success of this boiler is due to W. G. Freer, operating engineer of the plant, who made some interesting experiments on the effect of the amount of tube area exposed to radiation on the temperature of the fire. The lower row of water tubes was shielded by tiles for the purpose of giving sufficient heat-reflecting surface to maintain the desired furnace temperature for the working capacity of the boiler. The amount of surface was determined by trial. During the first trial runs too many tiles caused an excessive furnace temperature and too strong an upward draft into the flue passes. On the second trial, when for the purpose of experiment nearly all the tiles were removed, the furnace temperature was too low. By several adjustments, Freer finally obtained the best results when approximately 5 ft. of the length of the tubes was left exposed, out of a total length of 18 ft. This gave a temperature in the furnace of between 1,415 to 1,470°C. (2,600 and 2,700°F.). The effect

of this opening is evident from the fact that a 4 ft. opening gave too high a temperature, while a 6 ft. opening gave too low a temperature in the fire.

When first put in operation slag was produced in considerable quantities. This was found to be due to insufficient air for combustion, as carbon was found in the ash. An increased air supply corrected this.

Steam Locomotives.—One of the earlier boiler applications, for which pulverized coal was tried in the United States, was on locomotives. This has been mentioned in a general way on page 296. The small space available for burning coal in suspension in a locomotive firebox renders this application a difficult one and the combustion problems are accentuated. A number of locomotives have been operated successfully with pulverized coal* and it is interesting to consider the relative effects of a sufficient or insufficient air supply under the extreme conditions met with in this application, as described in the section on the chemistry of combustion.

The steaming capacity of large locomotives is often seriously limited by the inability of the firemen to shovel coal fast enough to maintain full steam pressure, and by the continual opening of the door which disturbs the uniformity of the draught. In the western States, where only poor grades of coal are available, this difficulty with hand firing has often led to the substitution of oil-burning engines on mountain grades. In this service it is difficult to burn oil efficiently when forcing the boilers. Pulverized coal has the same advantages as fuel oil in locomotive service in regard to stoking and it is claimed that efficient combustion can be maintained at high rates of burning.

When burning coal on grates, a great deal of combustible is lost in the form of smoke and cinders, and this is especially true in the case of some low-grade western coals.

Several American railroads have been experimenting with pulverized fuel on locomotives and Table LXXXIX gives a summary of some of the fuels which have been used.

When burning anthracite, a sufficient proportion of bituminous coal is mixed with it to bring the volatile content of the mixture up to about 15 per cent. This gives a fire which will remain ignited at low rates of burning, while the locomotive is standing still.

* Consult: "The Use of Pulverized Coal for Locomotive Operation," by V. Z. Caracristi, *Gen. Elec. Rev.*, Nov., 1917.

TABLE LXXXIX.*—ANALYSIS OF FUELS WHICH HAVE BEEN USED ON LOCOMOTIVES IN PULVERIZED FORM

Kind	Moisture	Volatile	Fixed carbon	Ash	Sulphur	B.t.u.	Fineness through	
							100 mesh	200 mesh
Illinois unwashed screenings...	3.70	35.25	48.74	10.61	1.70	12,400	99.66	97.25
B. R. & P. bituminous.....	0.88	25.67	63.05	10.40	1.64	13,912		
Brazilian bituminous.....	1.73	14.02	60.04	25.94	8.25	10,904	99.8	96.6
Texas lignite.....	21.52	33.08	29.28	16.12	1.97	7,801	97.2	88.0
Eagle Pass bituminous.....	0.65	33.45	40.10	26.43	0.84	8,845	98.8	91.8
Bankhead graphitic anthracite.	0.48	13.68	70.83	15.49	0.94		98.2	90.5
Calgary, B. C., lignite.....	8.84	33.97	54.63	11.40			98.7	90.5
Bituminous (1).....	0.50	29.50	60.00	10.00	1.50	13,750		86.0
Anthracite slush (2).....	1.00	6.00	71.00	22.00	2.50	11,250		86.0
Kentucky unwashed screenings.....	2.46	36.00	54.00	7.94	0.79	13,964		83.0

NOTE.—Locomotive using a mixture of 40 per cent of (1) and 60 per cent of (2).

The further use of pulverized coal on American railways has been delayed by the conditions arising from the war. A few locomotives, however, have recently been equipped by the Fuller Engineering Co. As a result of the pioneer work done in the United States, the Central Railway of Brazil has adopted pulverized coal on its lines running out of Rio de Janeiro and 80 locomotives are now in operation, using Lopulco equipment. Similar equipment is either ordered, or being installed, for 120 additional locomotives and the plans call for its use on 250 of the largest locomotives.

Before the war Brazil imported its coal from England. With this source of supply cut off, the country is dependent upon a precarious supply from the United States, or from Natal, South Africa, and is, therefore, endeavoring to utilize its own abundant resources of low-grade coals. These are not at all satisfactory for burning on grates but are being burned very successfully in pulverized form on locomotives. An analysis of one sample of Brazilian coal is given in Table LXXXIX. The volatile content is more frequently around 23 per cent and the ash, which consists of shale that is interbedded with thin seams of coal, also runs higher. It cannot be readily separated in mining the coal. Washing and pneumatic separation have been tried with only partial success.

The Brazilian coal mines are located near tide water in the neighborhood of Porto Alegre, in the province of Rio Grande do Sul, and the coal must be shipped in light draft vessels to Rio de Janeiro, 800 miles to the north. As Brazilian coal cannot be burned on these vessels, American coal is used for bunker fuel. Under these circumstances, and with the lack of vessels, only a limited amount of Brazilian coal is being shipped to Rio de Janeiro and many of the locomotives are burning American coal, both on grates and in pulverized form. After allowing for the cost of preparation, there has been effected a net saving of between 8 and 12 per cent in cost of fuel by burning American coal in pulverized form, as compared with hand firing. Also, the locomotives operate smokelessly with either American or Brazilian coal.*

COMBUSTION OF PULVERIZED FUEL

The preceding examples of pioneer experiences, regarding the respective effects of heat absorbing and heat reflecting surfaces on the temperature of the fire, will be supplemented by some general considerations regarding the combustion of pulverized fuel. The following will supplement the section on the effect of ash in steam coal on page 608.

Chemistry of Combustion.—In burning pulverized coal under water-tube boilers, with improper conditions for combustion, a sticky slag sometimes forms on the tubes. This is often due to insufficient air, or to a poor mixture of air and coal, which results in a local excess of fuel. The following description of the chemical actions involved in the combustion of pulverized fuel is taken from a paper by J. E. Muhlfeld on "Pulverized Fuel for Locomotives."†

As a 1-in. cube of coal exposes 6 sq. in. of area for absorbing oxygen and liberating heat, and when pulverized to the proper fineness will expose from 20 to 25 sq. ft. of area for oxidation, the first essential for complete combustion is the breaking up of the fuel into dry, minute, and uniform particles. Then by diffusing

* The author is indebted to the late Dr. H. D'A. Fonseca, engineering commissioner from the Brazilian Government, for information concerning Brazilian coal and its use on locomotives. Also to the Pulverized Fuel Equipment Corporation. The figures, etc., refer to the number of locomotives in operation in 1920.

† *J. Am. Soc. Mech. Eng.*, December, **1916**, 986.

these so that each may be surrounded with the right quantity of air for complete combustion, it will be possible to burn practically all of the available combustible, regardless of the percentage of non-combustible.

Of the non-combustibles, ash contains a mechanical mixture of silica, alumina, iron, lime, potassium, sodium, and magnesium. The "clinkering" and "honey-combing" of ash is one of the worst troubles to be contended with in the combustion of coal, and its formation may be either chemical or by fusion.

Clinker is of two kinds— "hard" and "soft."

"Hard clinker" is formed by the direct melting of some of the ash content. It hardens as it forms and usually gives but little trouble.

"Soft clinker" is formed by the slagging of the ash; it is either pasty or fluid, and steadily grows in size.

"Honeycomb" or "flue-sheet" clinker is formed by the condensation or coking of tarry matter or vapor as it strikes against the firebox sheets, and results in the accumulation of a relatively soft, light, ashy substance that grows or spreads over certain of the refractory or metal parts of the furnace.

With the use of pulverized fuel, the usual difficulties resulting from the formation of hard and soft clinker on grates are eliminated, and with the fuels containing certain intrinsic combinations of ferrous silicates which fuse at comparatively low temperatures 1,100 to 1,250°C. (2,000 to 2,300°F.), the honeycomb formation will result, when the proper air supply and combustion do not obtain, to produce ferric silicates, which fuse at relatively high temperatures, 1,370°C. (2,500°F.) and above. For example, during the process of combustion ferric sulphide (FeS_2), commonly known in fuel as iron pyrites, is reduced to ferrous sulphide (FeS) as a result of the chemical reduction illustrated by the following formula:

$$FeS_2 = FeS + S.$$

As ferrous sulphide (FeS) melts at a comparatively low temperature, 1,165°C. (2,150°F.), it may surround itself with fuel and ash and form a pasty mass which may act as a binder to collect other ferrous sulphide, fuel, and ash, all of which may tend to collect on, and adhere to, the hottest parts of the firebox sheets, such as staybolt heads, flue heads, and like parts which are higher in temperature than the melting point of ferrous sulphide and

the surrounding metal surfaces, while the temperature of the latter may be lower than the melting point of the ferrous sulphide.

The following formula shows the result of incomplete combustion owing to insufficient air:

$$2FeS + O_2 = 2FeO + 2S$$

By providing sufficient air through an excess supply, the following formula shows the result of complete combustion:

$$4FeS + 9O = 2Fe_2O_3 + 4SO_3$$

For this latter process an oxidizing atmosphere must at all times obtain in the firebox to prevent the reduction of ferric sulphide (FeS_2) to ferrous sulphide (FeS), as expressed in the first formula.

The ferrous sulphide, as has been shown, is the direct cause of honeycomb, for the reason that it produces ferrous oxide (FeO), which unites with the silica to form a honeycomb that is very fusible at temperatures over 1,300°C. (2,400°F.); whereas by the production of ferric oxide (Fe_2O_3), in combination with the silica present, a highly infusible clinker is formed.

As a general rule, an increase in the percentage of silica, alumina, and magnesium in the fuel matter will tend to decrease, while an increase in the percentage of iron, lime, potassium, and sodium in the fuel matter will tend to increase the fusibility of ash; but in every case a relatively high percentage of ferrous oxide (FeO), resulting from an insufficient supply of air for combustion, will be accompanied by honeycomb formation that will tend to adhere to various parts of the firebox.

W. G. Freer* states that, from his observations in burning pulverized coal under a stationary boiler, the slagging of the ash occurs when particles of unconsumed coal and coke are deposited in the ash. Even when such particles fall into powdery ash they appear to form a flux with the ash, and this is true with coals of either high- or low-sulphur content. Thus, the formation of sticky slag on the tubes is sometimes due to coke particles being deposited on the tubes along with powdery ash, and the remedy is to allow sufficient space for the complete combustion of the coarser particles before they reach the tubes. When coke particles fall in the hot ash they continue to burn with an insufficient air supply, and there is probably enough sulphur in most coals to form soft clinker, according to the reactions described.

* See page 680.

Fine Ash.—When sufficient air is supplied for combustion, the portion of the ash which is less fusible retains its originally finely divided state and is carried through the boiler tubes in the form of a dry powder which does not adhere to any surfaces. Fig. 160* is a photomicrograph of particles of ash collected in the damper chamber of a boiler. These particles contain practically no combustible matter and a large proportion of them are so fine that they are carried up the chimney and emitted in the form of a faint white haze which is carried in suspension in the wind for some time, like volcanic dust. It is claimed that this will stay in suspension in the atmosphere for a sufficient time to be carried far from the city where it is produced.

The high-ash content in some coals has given trouble by accumulating on horizontal baffles, in water-tube boilers, and in horizontal fire-tubes in return tubular boilers. With vertical baffles, however, no trouble is experienced in burning high-ash coals in suspension under water-tube boilers. The heat stored in the particles of ash is radiated to the tubes during the passage of the gases through the tubes. Thus the ash particles, carried in suspension, increase the sensible heat of the gases without appreciably increasing their volume or the tube surface necessary for cooling the gases to a given final temperature. This results, it is claimed, in an increased output from the boiler.

More evidence would be desirable in regard to the tendency of ash dust to settle in the vicinity of the plant. In some cases, especially when burning high ash coals, the ash carried up the stack has been deposited in the neighborhood.† In other cases, it has been claimed that no ash deposits have been found near plants where pulverized coal is burned. Where this fuel is burned in city power stations, it should be very desirable to install effective dust collectors in the stacks, owing to the critical attitude of the public towards public utility corporations.

In large plants the volume of the waste gases is tremendous and the Metropolitan type of cinder catcher (page 711) is the only one found satisfactory, by one of the large central stations equipped with stokers, after many experiments.

This indicates that dust collectors, to be practicable, must be of simple static types. A cyclone collector has recently been

* Reproduced by the courtesy of The Pulverized Fuel Equipment Corp.

† Consult: "Pulverized Fuel," by W. J. Dick, *Com. of Cons. of Canada*, 1919, 36.

tried at the Oneida St. station of the Milwaukee Electric Railway & Light Co. with good results.* It had been found that, in general, about one-third of the ash settled at the bottom of the furnace, another third in the combustion space below the second and third passes, and the final third found its way to the breaching and the stack. A considerable amount of this remaining third collected at the bottom of the smoke flue and at the base of the stack, only the finest ash floating out at the top of the chimney. By sending the final third of the dust that ordinarily reaches the stack through a cyclone separator, they had been able to collect 88 per cent of it, so that only 12 per cent of the final third of the ash floated out through the stack to the atmosphere. The ash was pulled out of the bottom of the furnace every twelve hours.

Another type of centrifugal collector which may be even more effective is the Taylor-Milliken dust arrester (page 603).

When starting a pulverized-coal fire in a cold furnace there is a little smoke emitted for a short time which consists, partly, of unconsumed fuel. After the furnace walls are hot, however, it can be operated without any smoke whatever, barring carelessness in adjusting the air supply. Smokeless operation is possible, even at high rates of burning, with properly designed furnaces.

Flames.†—The flame resulting from the deflagration of pulverized coal differs from that of other fuels in the larger combustion space required on account of its low combustibility, and the higher temperature due to the rapid breaking up of the solid structure of the coal particles. In general, the more inflammable the material or the higher the rate of oxidation, the smaller the space required for its combustion and the lower the average temperature that develops, also the shorter the flame.

"This condition is shown by the performance of explosives and the slow burning of gas, oxidation of iron, etc. The average temperature of combustion of gases in ordinary air is from 815 to 1,100°C. (1,500 to 2,000°F.), and, for a given amount of fuel consumed, the combustion takes place in a smaller space than that required for atomized oils, which begin to burn steadily at about 1,100°C. (2,000°F.). Experience shows that the

* HENRY KREISINGER, paper presented before the Smoke Prevention Assn., Chicago, October, 1920. *Power*, Oct. 19, 1920, 637.

† WELLES and JACOBI, *Mech. Eng.*, Sept., 1919.

deflagration of pulverized coal requires a still larger space and that the average temperatures developed by its combustion are much higher."

TABLE LXL.—APPROXIMATE COMBUSTION TEMPERATURES OF CARBON AND BITUMINOUS COAL AND THE RESULTING PERCENTAGES OF CO_2

Percentage of excess air	0	25	50	75	100	125
Combustion temperature, degrees Fahrenheit:						
Carbon	4,000	3,450	3,000	2,625	2,350	
Average bituminous coal	4,860	4,000	3,325	2,860	2,500	2,220
CO_2, per cent	20.8	16.5	13.8	11.8	10.2	

"Fuels are rendered more inflammable as they are brought to or carried beyond their ignition temperature and are more thoroughly mixed with the necessary oxygen.

"The proper velocity for the fuel mixture as determined by its inflammability can only be found by trial, and the condition to be fulfilled is that the base of the flame shall approach the outlet as closely as possible. A lower velocity may result in backfiring within the feed tubes, which are of appreciable dimensions. A higher velocity carries the mixture too far into the hearth before combustion begins, and has the effect of coking and consolidating the particles, which drop to the bottom of the hearth in the form of relatively large globules, thereby causing faulty combustion and loss of fuel. Coking of the combustible charge is very perceptible in connection with discharge outlets of large diameter such as are used in cement kilns. The action in this case has been attributed to more rapid combustion on the surface of the combustible jet, which has the effect of baking the core within (see Fig. 158). This difficulty has been overcome by using outlets in the form of a slot of the required cross-section, thereby exposing more surface to the hot gases in the hearth."

The above reference to the flat flame is of interest, in connection with boilers, because it is used in burning anthracite where time is required to ignite the particles. It was also used for spreading granulated coal laterally over a grate fire.

Preheating the Air for Combustion.—The possibilities of preheated air and gas have been mentioned on page 391, in connection with gas-fired boilers. Highly preheated air has not been used in connection with pulverized coal-fired boilers, at least to the extent of providing records of value, but it has been used to a limited extent in industrial furnaces. In open-hearth

steel furnaces the blast is preheated to approximately 1,100°C. (2,000°F.).

It would seem that preheated air should offer more possibilities in connection with boilers fired with pulverized coal, than when raw coal is burned on grates or stokers, owing to the absence of metallic grates or mechanism in the furnace. Higher air temperatures may be obtained by passing the air through passages in the furnace walls. This will cool the brickwork and may render practicable the use of a furnace lining of carborundum bricks. These can withstand higher temperatures and have a greater thermal conductivity. Some initial heating of the air may be accomplished by passing it through an external jacket on the outside of the furnace or by waste heat from the flue gases.

Carborundum bricks are being used in stoker-fired furnaces to a limited extent. A cheaper type of lining can be made with ordinary firebricks laid with high temperature cement. Refractory qualities more nearly approaching those of carborundum bricks can be made by lining the furnace with a mixture of "carbosand" (a low grade carborundum) mixed with high-temperature cement as a binder.*

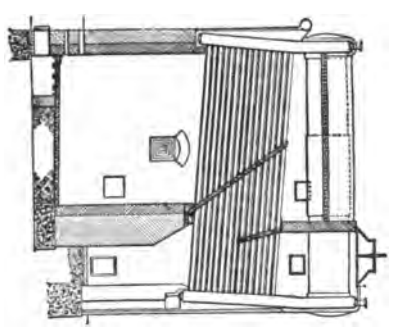


FIG. 155.—Combustion chamber enlarged for oil burning by Turner baffles.

Preheated air should considerably accelerate the ignition and burning of finely-divided fuels in suspension, especially in the case of fuels with a low volatile content. The secondary or volume air may be preheated to as high a temperature as is practicable. Where primary air is used for carrying the coal to the burner, it may be preheated to a temperature below the fusion point of the coal. The particles can be heated and gas distilled from them, which will aid in their rapid deflagration. A type of burner must be used which will not permit of back-firing, the volume air mixing with the fuel not far from the tip of the tuyere, while the primary air can carry the coal with

* Carbosand and hytempite cement are made by the Quigley Furnace Specialties Co.; "Flame Brand" cement is made by the King Refractories Co. Several grades are made by the Johns-Manville Co.

a high velocity. The expanded volume of the hot air should enable it to carry the coal in suspension with a greater separation of the particles and facilitate the access of oxygen to each particle.*

Control of Furnace Temperature.—In a furnace designed for operating with the combustion air introduced at room temperature, the substitution of preheated air and fuel in similar proportions will naturally result in a higher furnace temperature. This may be compensated for by increasing the area of heat absorbing surface exposed to direct radiation from the fire, as indicated by the experiments of Hunt (pages 665 to 667) and Freer (pages 680 and 681).

The upper limit of temperatures is reached when the furnace lining softens to the point where it may be destroyed by local erosion or by complete collapse (see page 517). The best construction for operating at extremely high temperature involves the cooling of the refractories, by air or by water tubes, as in the lower baffle in the American Locomotive Works boiler (Fig. 155) and in the Bettington boiler (Fig. 154). In the latter case the furnace temperature was so high that the refractories sometimes suffered from melting and erosion; and it was this limitation, apparently, which has prevented the more general adoption of this interesting type of boiler.

The lower limit of temperature is determined by the necessity for the prompt ignition of the incoming fuel. If the temperature is too low, there will be a loss of fuel from incomplete combustion, and unconsumed fuel will be carried through the boiler and lost. The ignition of the incoming fuel takes place by—

1. Propagation of the flame, *i.e.*, by the fire travelling from particle to particle.
2. Radiant heat from the flame.
3. Reflected heat from the walls.

In the earlier experiments in burning anthracite, the furnace temperatures required for ignition were so high that the refractories suffered by erosion. This has been overcome by thoroughly exposing the incoming fuel to radiant heat (see page 698). The use of pre-heated air should also render extreme furnace temperatures unnecessary.

Another important factor is the proportion of air to fuel. The effect of different percentages of excess air, on the the-

* Consult WELLES and JACOBI, *Mech. Eng.*, September, 1919, 746.

oretical temperature resulting from combustion, is clearly shown in Table LXL. The actual temperatures in the furnace are modified according to the freedom with which the heat may be transferred by radiation to heat absorbing surfaces. Economic operation calls for the use of as little excess air as possible. Practical operating conditions require a safe margin to avoid trouble from slag formation due to excess fuel. This margin may be in the

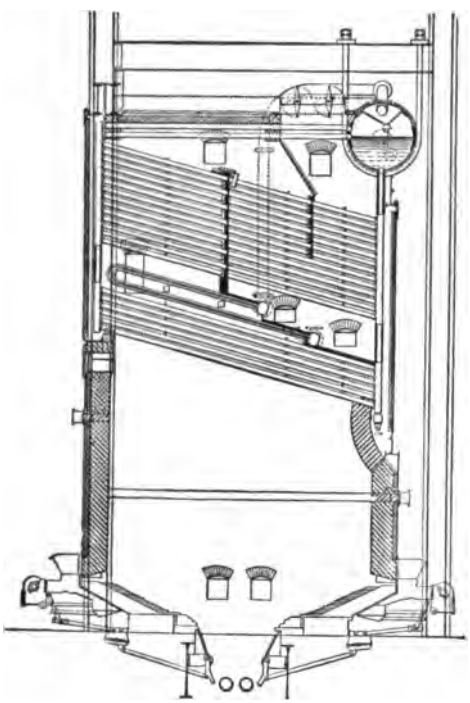


FIG. 156.—Recent development of the two deck, cross drum Babcock & Wilcox boiler.

neighborhood of from 10 to 25 per cent with pulverized coal, as compared with 50 per cent and upward for stokers This latter percentage may be reduced by the use of efficient automatic devices for combustion control (see page 751). In burning coal on grates, at least 100 per cent excess air is required, owing to the difficulty of distributing the air evenly over the entire fuel bed. Furnace temperatures should be kept down by free radiation to the evaporating surfaces, by properly proportioning the design of

the boiler and furnace, rather than by operating with excess air. This will conduce to maximum efficiency and output.

There has been a gradual advance in this direction in stoker-fired boilers during the past few years, and the boilers have also been set higher above the fire bed in order to provide sufficient space for the complete combustion of the gases. With either stokers or pulverized coal, a sticky slag is liable to adhere to the lower tubes under the following conditions:

1. When the furnace volume is too small to allow combustion to be completed before the flame reaches the tubes. The fuel and air are not apt to be thoroughly mixed under these conditions and the fuel is in excess at some points where combustion is in progress.

2. When the gases pass the first tubes at too high a velocity they are liable to carry partially burned fuel with them. This can only occur when the evaporating surface exposed to direct radiation is of too limited area.

In the Stirling type of boiler (Fig. 168) the tubes are inclined to a steep angle and present a very large surface to the radiant heat. In the various types of boilers with horizontal tubes only a part of the length of the lower tubes are exposed to radiation (Fig. 167). Nevertheless, in the standard type of Babcock and Wilcox boiler about 66 per cent of the heat transfer takes place by radiation when the boiler is operated at its rated capacity. As these boilers maintain good efficiencies from this load up to about 175 per cent of rating, they are often operated at about this point. The heat transferred by direct radiation, however, remains approximately the same while the additional heat is transferred by convection to the other tubes, the increased rate of heat transfer being due to the increased velocity with which the larger volume of gases pass the tubes. At this load about 38 per cent of the total heat transfer will take place by radiation.

In each case the furnace temperature is assumed to be 1,470°C. (2,700°F.). With 4 in. tubes spaced 7 in. between centers the rate of evaporation is slightly in excess of 80 lb. of steam per hour from and at 100°C. (212°F.), per lineal foot of the tubes in the zone of direct radiation.*

Effect of Furnace Temperature on the Ash.—In spite of this high rate of heat transfer, there are limitations to the ratings at

* Consult: "Waste Heat Boilers," by D. S. JACOBUS and A. D. PRATT, *Proc. Eng. Soc. W. Penna.*, May, **1920.**

which the horizontal type of water-tube boiler with vertical baffles may be operated with pulverized coal without developing excessive temperatures in the furnaces. The troubles accompanying high temperatures are as follows: (1) Slagging of the ash, which makes it difficult to remove after it has solidified. (2) Erosion and melting of refractories. (3) Adherence of slag on side walls. Such troubles are dependent, in part, on furnace design and volume, as well as upon the kind of coal burned, and the composition and fusibility of the ash, as well as the proportion of ash in the coal.

The tests of the installation at Lebanon, Pa. (see pages 707 to 711) furnish an interesting example.

With some fuels, however, it has been found desirable to maintain sufficiently high furnace temperatures to slag the ash and yet avoid trouble with refractories. This may be desirable when a coal is always available which has an ash of low melting-point and some anthracites are being burned in this way. The furnace bottom is then designed to allow of draining off the slag before it can solidify.

In the two plants operated by the Milwaukee Electric Railway & Light Co. a water screen is installed near the bottom of the furnaces. This consists of several water tubes connected to the main boiler and its function is to cool the small particles of ash as they fall. It is intended particularly for use in connection with coals having an ash of low fusing point.

Furnace Volume.—According to Savage,* it has been shown by various tests, that capacity is in direct proportion to furnace volume, and that, in the furnaces upon which it has been possible so far to make determinations, the most efficient rates of combustion have been at from 1 to 1.5 pounds per hour per cubic foot of furnace volume, although efficiencies change very little in a properly designed furnace up to 2 pounds per cubic foot. Satisfactory operating results can be secured at from 0.5 pounds to 2 pounds per cubic foot, which permits a very wide operating range.

Baffling of Horizontal Water Tube Boilers.—The operation of stoker-fired boilers of this general type has been considerably improved, in some instances, by the use of inclined baffles between the first and second passes (Fig. 156). The bridge wall

* "The Use of Powdered Fuel Under Steam Boilers," by H. D. Savage, *Am. Iron & Steel Inst.*, May 27, 1921.

of the furnace is located further to the rear, the dust chamber under the rear passes being reduced in size to make room for a deeper furnace. This makes possible an increase of about 50 per cent in the area of the tubes exposed to direct radiation. The inclined baffle has a slope of about 45° with respect to the tubes. The lower end rests on the bridge wall, while the upper end occupies about the same position as the top of the old vertical baffle. The baffle between the second and third passes is shortened at its lower edge to allow a sufficient area for the gases to leave the second pass and enter the third. Inclined baffles of the poured type are made from a special cement prepared by the Johns-Manville Co. Turner baffles are built from moulded blocks of a special design and are furnished by the Engineer Co. Inclined baffles of the poured type, with a steep inclination, have been used on stoker-fired boilers in the power station of the General Electric Co., at Schenectady, for 4 years. This installation, which was probably the first of its kind, was made by A. W. Nisbet, the superintendent of this station. A little more care and skill are required for making them, as compared with the vertical baffles, and this is the only reason for the more general use of the latter. Incidentally, the gas currents keep the tube surfaces cleaner, when inclined baffles are used, owing to the elimination of eddies.

The Babcock & Wilcox Co. has recently developed a new type of horizontal water tube boiler, one form of which is shown in Fig. 156. This is a double-deck type, the upper deck being quite similar to the conventional type with one or two vertical baffles, according to the number of passes desired. The tubes in this deck all constitute indirect heating surface.

The lower deck is made up of six rows of tubes which constitute a single pass, the whole length of the lower tubes being exposed to direct radiation. A space is left between the two decks for the superheater coils and the first baffle is extended horizontally over the top of the tubes of the lower deck.

In Fig. 157 the furnace is of the duplex type and is equipped with two underfeed stokers, both of which discharge their ashes onto a centrally located clinker-grinder. The furnace is of ample volume, and the large area of evaporating surface exposed to the radiant heat ensures low furnace temperatures and long life for the refractories. This particular boiler is designed for 275 lb. steam pressure and 124°C. (225°F.) superheat, and may be con-

structed in units with a heating surface up to 23,050 sq. ft., being intended for base load stations.* Smaller boilers of this general type have also been designed.

In the experiments noted on pages 680 and 681, in connection with the boiler shown in Fig. 155, it was found that the exposure of the full length of the lower tubes to radiation reduced the furnace temperature to a point where ignition of the incoming fuel became difficult, or where incomplete combustion resulted. In the case of larger boilers and deeper furnaces, however, the volume of the fire is such that this limitation should disappear.

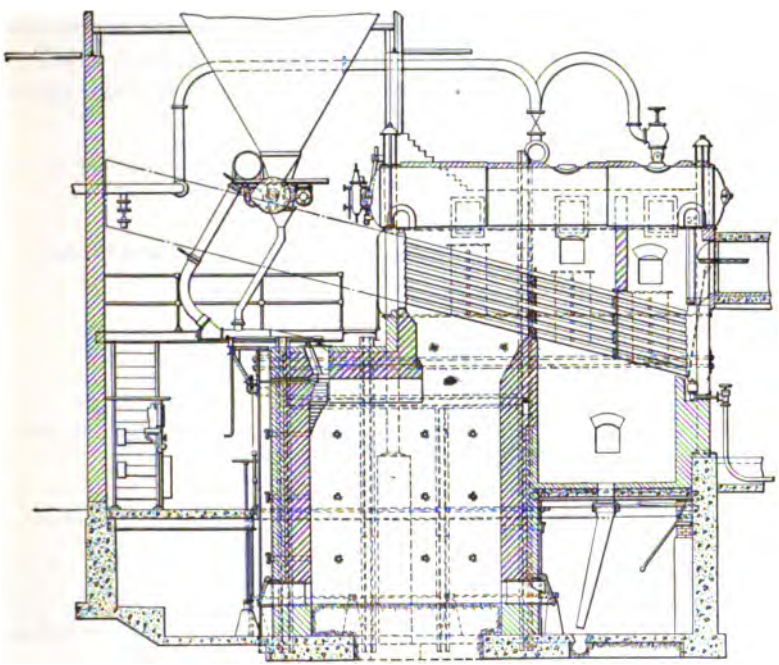


FIG. 157.—Typical cross-section of pulverized fuel installation, B. & W. setting.

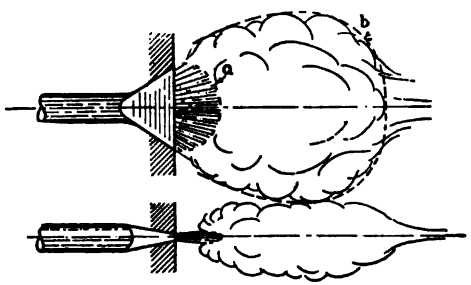
RECENT BOILER-FIRING INSTALLATIONS

The *Fuller-Lehigh System* is clearly illustrated in Figs. 167 and 168. This system was installed in one of the first boiler plants to be operated entirely with pulverized coal, in 1916, in the shops of the Missouri, Kansas and Texas Railroad, at Parsons, Kan. Table LXLI gives analyses of fuels which were successfully burned in this plant.

* *Power*, Dec. 7, **1920**, 891. (Figure 156 is from p. 892.)

TABLE LXLI

Kind of fuel	Lignite	Cherokee slack	Semi-anthracite
Source of fuel	Texas	South Kansas	Kansas
Analysis, dry basis:			
Volatile	61.5	32.4	22.3
Fixed carbon	24.7	49.6	60.0
Ash	13.8	18.0	17.8
B.t.u.	10,675.0	12,185.0	12,625.0
Sulphur (sep.)	1.0	5.1	4.1
Moisture	17.0	1.0	0.3
B.t.u. as fired	8,854.0	12,056.0	12,587.0



Flat Flame.



Cylindrical Flame

FIGS. 158 and 159.—Approximate shapes of flat and cylindrical flames of the same capacity and under similar conditions. *a*, zone of initial oxidation; *b*, zone of complete oxidation. Note the length of zone *a* in the cylindrical flame. Coking of powder has been observed to take place within this zone through baking.

When running a test with Texas lignite, the dryer was not of sufficient capacity to dry it to more than 17 per cent moisture content, but it was pulverized and burned successfully in this state (see pages 562 and 563). Apparently, it was as fluid when pulverized as the semi-anthracite.

The ash from the lignite and semianthracite did not fuse and there was a small deposit in the pit of a yellow sandy looking ash. The analysis of the semi anthracite would appear to class it more as a semibituminous and it burned with an exceptionally clear fire. It was shipped from the mine in a fine state, which

rendered it unsalable. The Cherokee slack had a fusible ash which collected in the pit in molten form. This was the fuel regularly burned at the plant and the ash content sometimes ran as high as 26 per cent.

This plant was the first boiler installation to use pulverized coal on a considerable scale and to operate successfully and economically in continuous service, 24 hr. daily, for any considerable length of time. The success of this plant emphasized the importance of large combustion chambers, the failure of many previous installations being chargeable to attempts at burning pulverized fuel in too small a furnace.

Table LXLII contains a list of tests made on boiler plants using this system.

TABLE LXLII.—BOILER TESTS*

Date of test	Duration of test	Rating, per cent	Coal used—Source	B.t.u. per pound as fired	Ash, per cent	Efficiency maintained
Ash Grove Lime & Portland Cement Co., Chanute, Kan.						
Dec. 12, 1917	5 hr.	125	Kan. bit.	12,500	18.25	84.0
Jan. 28, 1918	25 days	100	Kan. bit.	11,435		78.1
M. K. & T. R. R. Co., Parsons, Kan.						
April 26, 1918	6 hr.	...	Kan. bit.	12,900	17.5	80.3
April 28, 1918	6 hr.	131	Kan. bit.	12,289	17.5	80.9
British Columbia Sugar Refining Co., Ltd., Vancouver, B. C.						
April 7, 1919	4 hr.	125	Nanaimo slack	9,364	28.4	83.3
April 17, 1919	5 hr.	160	Nanaimo slack	10,050	24.3	77.1
United Verde Extension Mining Co., Warren, Ariz.						
Sept. 24, 1918	6 days	155	Gallup, N. M.	10,680	14.3	79.5
† Allentown Portland Cement Co., Evansville, Pa.						
June 7–8, 1920	22.8 hr.	111	Pa. bit.	13,260	11.2	77.3
This test was on an old Rust vertical boiler.						

* From "Pulverized Coal for Stationary Boilers," by F. A. SHEFFLER and H. G. BARNHURST. *Mech. Eng.*, August, 1919, 650.

† From company *Bulletin*.

The Fuller system is now (1920) being used for firing boilers in a number of plants. New installations are being made in 11 plants, which will be put in operation in 1921.

The Hanna System has been developed for burning anthracite silt at the mines in the anthracite district in eastern Pennsylvania. The initial experiments were conducted on a boiler at the Susquehanna Collieries Co., operated by M. A. Hanna & Co., Agents. The data on three tests are given in Table LXLIII.

TABLE LXLIII.—TESTS OF EXPERIMENTAL BOILER AT LYKENS, PA.

Type of boiler... B. & W. inclined header, 3 pass, 7 tubes high by 16 tubes wide.
Heating surface . 2,357 sq. ft.
Stack..... 64 ft. high by 5 ft. diameter.

Date of test	April 23, 1919	April 24, 1919	Aug. 4, 1919
Duration of test	6.2 hr.	5.92 hr.	5.88 hr.
Steam pressure, gage	116.6	111.1	107.1
Draft, inches of water:			
Bottom of furnace	0.196	0.186	0.154
Top of furnace	0.054	0.044	0.033
Top of third pass	0.116	0.110	0.096
Flue behind boiler	0.329	0.327	0.35
Temperature of			
Feed water	194°F.	191°F.	197°F.
Flue gases	562°F.	574°F.	630°F.
Fuel	Coke breeze	Anthracite slush	No. 2 and 3 Bwt.
Source	Dover, Ohio	Nanticoke, Pa.	Lykens, Pa.
Analysis:			
Moisture	1.0	1.0	1.25
Volatile	9.9	7.2	8.6
Fixed carbon	73.8	64.7	78.3
Ash	15.4	27.1	11.9
B.t.u. per pound, dry	12,190.0	10,008.0	13,289.0
Weight, as fired	6,918.0	7,706.0	6,564.0
Fineness, per cent.:			
Through 100 mesh	98.3	88.5	99.3
Through 200 mesh	92.6	80.8	90.7
Per cent of rating developed	121.6	107.5	141.3
Water pumped to boiler per pound of fuel as fired	8.86	6.7	10.33
Equivalent evaporation of 1 lb. of dry fuel f & a 212°F	9.5	7.2	11.05
Combined efficiency of furnace and boiler, per cent	75.5	69.8	80.7
CO_2 in flue gas, per cent	12.0	13.1	10.0

TABLE LXLIII.—(*Continued*)

Analysis of ash deposited at top of first pass:			
Volatile	2.0	1.7	3.1
F. C.	12.5	20.9	26.6
Ash	85.5	77.4	70.3

The general layout of the furnace is shown in Fig. 157. About one-half the furnace protrudes beyond the boiler front and the burner is located in the top of this Dutch oven. The primary air, carrying the coal, issues from a broad slit which spreads it out into a flat flame surrounded by induced secondary air. When operat-

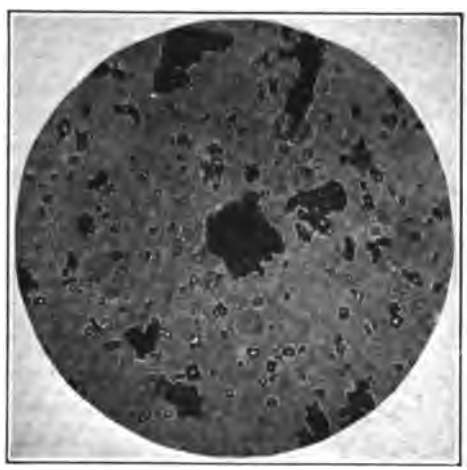


FIG. 160.—Ash from pulverized coal (magnified 840 diameters), collected in the damper chamber of a stationary boiler. (*Published through the courtesy of the Pulverized Fuel Equipment Corporation.*)

ing at full load, the flame shoots downward at an angle of about 20° from the vertical and in the direction of the center of the furnace. The gases expand and lose velocity until they are drawn upwards by the stack draught and through the tubes. Some air also enters the furnace at the bottom.

The U-shaped path of travel is sufficiently long to allow time for complete combustion, besides which it exposes the incoming flat sheet of fuel to the radiant heat from the rising part of the flame. This greatly facilitates the ignition of low-volatile fuels. When operating at light loads, the pressure and velocity of the carrying air are reduced and a deflector plate is used to change the angle at which the flame enters the furnace.

The flame then dives less deeply into the furnace and the depth of the hot zone is less, and also the radiation loss from the walls. The velocity of the flame being less, the time of travel for the particles of coal through the shorter path is about the same.

The ash analysis from the top of the first pass is hardly representative and the particles deposited there include coarse fuel, while the fine dust carried up the stack probably contains but little carbon. When the author examined this furnace, the bottom was covered with a clean sandy ash of a light-yellow color. The experiments made with this boiler have shown that it is practicable to burn any grade of anthracite, regardless of the volatile content.

Figure 157 illustrates the furnace for a new installation made in 1919 as a result of the success of the Lykens experimental boiler. A new boiler plant has been built from this design at the colliery of the Lytle Coal Co., at Lytle, Pa., and is operated entirely with pulverized anthracite silt. This is the first commercial installation to burn pulverized anthracite exclusively.

This plant has been operating more than a year. Full operation has been delayed by the necessity for testing different types of mills to find a satisfactory type for grinding this fuel. It has also been necessary to do considerable experimental work on the furnaces with a view to operating the boilers at high rates of driving (see page 689). Special provision has been made to take care of the slagging of the ash.

In the type of furnace used at this plant, the ash is deposited on a steeply sloping bottom where it is removed continuously. This furnace has been operated continuously at from 160 to 200 per cent of boiler rating and, for shorter periods, at ratings of from 300 to 400 per cent. Certain boilers have been operated continuously at these higher ratings for several days at a time, showing that it is perfectly practicable as far as the boiler is concerned. The furnace temperatures developed in this particular setting, however, are sufficiently high to limit the life of the refractories. Nevertheless, the results attained indicate that it will be possible to operate successfully at high ratings with properly designed settings (see page 693).

The Quigley system is used for burning pulverized coal under boilers in the steel mill of the Falcon Steel Co., at Niles, Ohio,* fuel from the same milling plant being used for firing metallur-

* See page 528.

gical furnaces. An installation is being made, at the time of writing, for burning anthracite in the Mt. Vernon Street power station of the Philadelphia Rapid Transit Co. This is an old station of 7,500-kw. capacity, located in the business district and used for carrying peak loads.

The present installation contains 20 B. & W. boilers of 375-hp. rating. It is estimated that the load can be carried by 10 of these boilers when each is equipped for burning 3,000 lb. of fuel per hour. The fuel used will be silt dredged from the Schuylkill river. It will be pulverized in Raymond mills and conveyed to the boilers by the air transport system (page 637). The blowing tank is of 5 tons capacity per charge and is mounted on a scale with a quick reading dial to ensure accurate records of the amount of fuel supplied to each boiler. The first boiler has been in operation for about a year.

In the initial design a furnace volume of 1,542 cubic feet was used; the boiler having 3,917 sq. ft. of heating surface. A 12-hour test showed an efficiency of 69 per cent for boiler and furnace, the temperature of the gases leaving the boiler being 230°C. (447°F.). There was quite a little unburned carbon in the ash, so the Rapid Transit Co.'s engineers tried out a furnace of different design for comparison. The volume was reduced to 800 cu. ft. and a multi-mix type of burner was used, the idea being that the original furnace was serving partly as a mixing chamber. The new burner was surrounded by an ignition chamber and was designed to mix the fuel and air before they entered this chamber.

The revised furnace was successful in reducing the percentage of carbon in the ash, but it failed to equal the performance of the original furnace in other respects. The flue gases left the boiler at a temperature 253°C. (487°F.). It has, therefore, been decided to return to the original furnace with the addition of an ignition chamber. The burners will be located nearer the bottom, as was the case in the second furnace.*

The *Holbeck System* has been installed for firing a few boilers by the Bounot Company.

The *Lopulco System.*—Some recent tests of boilers equipped with this sytem, and burning pulverized bituminous coal, are given in Table LXLIV.

The Pulverized Fuel Equipment Company has also made

* "Burning Anthracite Mine Waste Efficiently," by O. M. RAU, *Power*, **54**, 828 (1921).

extensive experiments in burning anthracite,* one grade which was burned successfully being graphitic anthracite from Rhode Island, which is difficult to burn on grates. Table LXLV gives data on a test made in a Lopulco furnace at the Lima Locomotive Works, at Lima, Ind. The furnace was designed for bituminous coal, but was the most available one for making a test on an anthracite from Korea.

The coal burned in this test was a finely divided anthracite which is too friable and contains too much dust for burning on grates or stokers. The residual carbon in the flue dust was considered to be due to the fact that the furnace was designed for burning high volatile coal. As a result of this test, the Oriental

TABLE LXLIV.—TWENTY-FOUR-HOUR TESTS OF EDGEMOOR BOILERS AT PLANT OF MORRIS & COMPANY, OKLAHOMA CITY, OKLA.

Date	Feb 24–25, 1920			March 1–2, 1920		
Heating surface	3,000 sq ft.			4,680 sq. ft.		
Furnace	Lopulco			Lopulco		
Average temperatures:						
Room	84.0°F.			71.1°F.		
Feed water	95.0°F.			82.5°F.		
Flue gases	552.7°F.			582.2°F.		
Average steam pressure	136.8 lb. gage			140.4 lb. gage		
Vacuum (draft):						
Combustion chamber	0.031 in. water			0.421 in. water		
Breeching uptake	0.653 in. water			0.149 in. water		
Gas analysis:	MAXIMUM	MINIMUM	AVERAGE	MAXIMUM	MINIMUM	AVERAGE
Per cent CO_2	15.0	11.6	13.6	16.2	12.7	14.8
Per cent CO	0.0	0.0	0.0	Trace on reading 5		
Per cent O	7.0	3.6	5.0	4.9	1.6	3.2
Fuel fired per hour	1,556			1,529.7		
Pounds steam per hour	13,013			21,600		
Evaporation (f & a 212°F.)	9.3 lb. water per pound coal			9.7 lb.		
Per cent. of rating	140.0			152.0		
Boiler efficiency, per cent	81.6			83.3		
Fuel used	Screenings from McAlester, Okla					
B.t.u. per pound (as received)	11,038			11,315		
Accumulation of						
Slag on tubes	Very little			None		
Ash in settings	Very little			Very little		
Smoke	Light			Light		

* Consult: "Powdered Coal Efficiencies," by H. D. SAVAGE, *Gas Age*, June 25, 1920, 541.

TABLE LXLV.*—TEST OF HEIJO ANTHRACITE, FROM PING YANG DISTRICT, KOREA

Heine boiler	Heating surface, 4,862 sq. ft.	
Furnace	Lopulco	
Duration of test	6 hr.	
Date	Nov. 9, 1919	
Steam pressure, pounds per square inch, gage		142.8
Temperatures, Fahrenheit:		
Steam		362.0
Feed water		136.5
Gases leaving boiler		447.0
Air entering furnace		65.5
Furnace		2,420.0
Draft, inches of water:		
Between damper and boiler		0.15
In furnace		0.04
Hourly quantities and rates, pounds:		
Dry coal		1,786.5
Evaporation (cor. for steam qual.), per pound of coal, as fired		9.53
Equivalent evaporation, f & a, 212° ditto		10.61
Per cent. of rating developed		115.0
Efficiency, per cent.		79.6
Flue gas analysis:		
CO_2		14.34
O_2		4.81
CO		0.0
No smoke		
Coal analysis, per cent.:	As Fired	Dry
Moisture	2.15	
Volatile	10.4	10.6
Fixed carbon	74.5	76.0
Ash	13.0	13.4
Sulphur (separate det.)	0.9	0.9
Flue dust:		
Per cent combustible		7.9
Fusing temperature, degrees Fahrenheit		2,084.0

Development Co. recently has ordered equipment for burning pulverized anthracite in a power plant in Seoule, Korea.

The largest boiler units in operation, at the time of writing, are installed in the new power plant of the Ford Motor Co. at River Rouge, Mich. The first two boilers have been in operation for several months. The boilers in this plant are all equipped for burning pulverized coal, either alone or simultaneously with blast furnace gas. The economic advantages of this combination

* The writer is indebted to T. Narita, of the Oriental Development Company, Seoule, Korea, for data.

have been discussed in Chap. V. The statistics of the boilers are given in Table LXLVI. They are designed to operate at loads up to 450 per cent of normal rating. The normal supply of blast furnace gas will be sufficient to operate the boilers at normal rating with the aid of a small pulverized-coal pilot flame; the function of the latter being to furnish incandescent particles of solid matter which will mix the gas and promote rapid and complete combustion. The portion of the load in excess of normal rating will be carried with pulverized coal and, when no gas is available, the entire load will be carried with coal. Burners of the Lopulco vertical type (pages 651 and 652) are introduced on both sides of the furnace.

TABLE LXLVI.—STATISTICS OF THE BOILER PLANT IN THE POWER STATION OF THE FORD MOTOR CO., DETROIT, MICH.*

Number of boilers	4
Heating surface of each unit (exclusive of superheater)	26,470 sq. ft.
Diameter of water tubes	3.25 in.
Four main drums	5 ft. diameter by 25.8 ft. long
One steam drum	3 ft. diameter by 23 ft. 8.25 in. long
Steam pressure	240 lb.
Superheat	200°F.
Furnace, "Lopulco," 23 ft. side by 24 ft. deep by 55.3 ft. high	
Combustion space, exclusive of ashpits	13,200 cu. ft.
Fuel	Pulverized coal and blast-furnace gas
Floor space occupied	29 ft. by 31 ft.
Height from ashpit to top of superheater piping, approximately	83 ft.
One stack for each boiler:	
Inside diameter	11 ft.
Height above ashpit floor	352 ft.
Natural draft.	

The gas is introduced horizontally at a lower level than the coal and through the medium of a specially designed grid burner. The results obtained with this burner so far have been extremely satisfactory, as the boilers were operated on gas alone for several months and ratings of around 175 per cent were obtained. When burning pulverized coal and gas simultaneously, the gas flame rises through a zone filled with incandescent particles of coal or

* From data furnished by the builders, the George T. Ladd Co., Pittsburgh, Pa.

ash, which ensure complete combustion of the lean gas. In the grid burner the gas and air are admitted in alternation through vertical slits.

Taking into account the irregular shape of the furnace, the volume approximates 0.5 cu. ft. per square foot of steam-making surface. The boilers have been designed with a view to operating normally at 250 per cent of rating. The following data on the relation of fuel consumption to furnace volume are estimated on the basis of 4 lb. of coal per hour per rated boiler horsepower (or per 10 sq. ft. of boiler-heating surface).

PER CENT OF RATING	LBS. COAL PER HR. PER RATED HP.	CU. FT. FURNACE VOLUME PER LB. COAL PER HR.
100	4	1.25
250	10	0.5

Two of the boilers have been in operation for several months on pulverized coal, at ratings up to 250 per cent of normal, and no particular trouble has developed. The coal has been burned without drying. Plans are being made to utilize coke breeze, which is available in large quantities. This contains 15 per cent of moisture, which will necessitate drying.*

The general layout of the boiler plant in the Oneida Street Station of the Milwaukee Electric Railway & Light Co., is shown in Fig. 161. The milling plant was located in the most available space, which was on the upper floor of the building. It contains one Ruggles-Coles dryer, two Raymond roller mills and a screw conveyor system.

The furnaces operate under natural draft, the greater part of the air being induced through various openings in the furnace front, through the vertical burner or through a lower damper. Air entering at the latter point forms a cool blanket over the bottom of the furnace, through which molten slag must fall and be solidified before it reaches the floor. The blower on the main floor supplies the primary air for carrying the coal at pressures of from 5 to 8 oz. The downward playing flame is gradually diverted by meeting currents of incoming air and is finally deflected into a horizontal path, by the incoming stream of cool air at the bottom, until it is drawn upwards by the stack draft. The burner system is described on pages 651 and 652.

* "Burning Powdered Coal at River Rouge," by T. WILSON, *Power*, **54** (1921), 664.

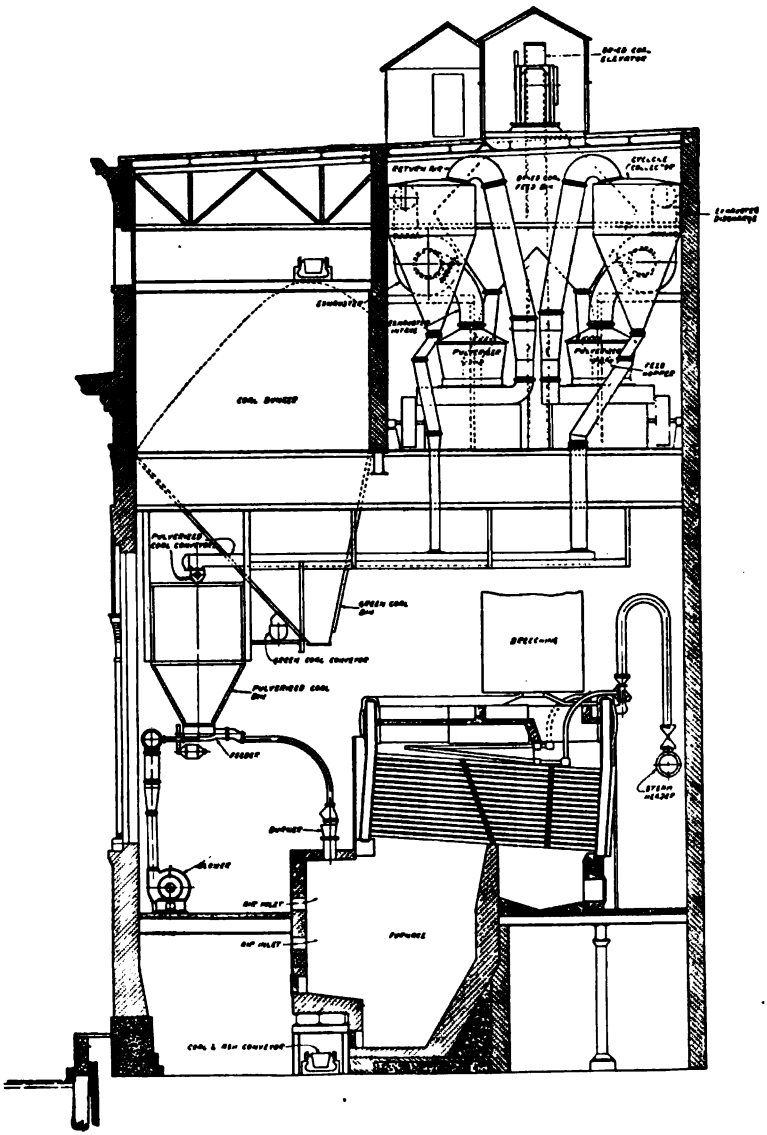


FIG. 161.—Cross-section through the Oneida Street boiler plant of the Milwaukee Electric Railway & Light Company.

The tests on the Lopulco installation at the new Lakeside station at Milwaukee are summarized on page 735.

The author is indebted to V. Z. Caracristi, H. D. Savage and others, connected with the Pulverized Fuel Equipment Corp. and Combustion Engineering Corp., for information and data relating to the preparation and burning of pulverized coal.

Bethlehem Steel Co., Lebanon, Pa.*—The second boiler installation to be equipped, primarily, for burning pulverized anthracite was started in 1920 at the Lebanon Works of the Bethlehem Steel Co., where pulverized coal has been burned in heating furnaces for many years (page 517).

This boiler installation, consisting of four 520-hp. Babcock and Wilcox boilers, was designed and built for the burning of pulverized coal. It is equipped with superheaters and economizers and is thoroughly modern in every respect. The general design, in the boiler settings and burners, is very similar to that of M. A. Hanna & Co. (Fig. 159).

Each boiler has a Uehling CO_2 recorder, Republic flow meter and recording thermometers on the water lines, steam lines and gas outlets from the economizer to the stack. In this way a close watch can always be kept over the operation of the plant, insuring economical operation.

During the tests additional instruments were used where necessary. The coal, which ordinarily is fed by gravity from the bunkers to a screw conveyor which feeds the burner, was by-passed from the bunker to two wooden tanks mounted on platform scales. Here the coal was weighed and fed from each box in turn, by a screw conveyor connected to the bottom of the box, to the regular line leading to the burner. Air from the blast fan is admitted in the end of this line and picks up the coal as it enters from the screw feeder and carries it to the burner. This air supplies only a small part of the oxygen needed for combustion. The balance of the air needed is admitted through doors located around the bottom of the combustion chamber. The air being admitted in this way serves the two-fold purpose of supplying the oxygen necessary for combustion and also of cooling the bottom and walls of the furnace, thus preventing slagging and fusing of the brickwork. The burner is placed in the top of the

*The authors are indebted to J. A. KINNEY, engineer of the Lebanon Works, and others for a report on which most of this account is based.

furnace, thus throwing the flame downward, and this also helps to preserve the furnace lining as the flame does not impinge directly upon any part of the brickwork.

During the tests the air supply was regulated in three different ways; namely, by use of the slide damper in the blast line, by the opening of the doors in the combustion chamber, and by the use of the stack damper. This final method was found to be the best; for, as the damper was opened and a greater draft produced in the furnace, more air was drawn in. The damper was set to carry about 10 per cent of CO_2, as it was found that the best results were obtained when running this way. With a higher CO_2 content, the furnace temperature became too great, causing slagging and fusing of the brickwork, and the evaporation rate fell off. To obtain the high CO_2, it was necessary to close down on the stack damper, thus decreasing the velocity of the gases passing through the boiler. This caused the transfer of heat from the gases to the water to be slower, thus cutting down the evaporation for the same amount of coal. In this way it was determined that a better efficiency was secured with about 10 per cent of CO_2 than with 13 to 15 per cent. When the damper was closed down to obtain higher CO_2, the stack gave off heavy black smoke, and, as the damper was opened, the CO_2 dropped and the stack cleared up till at 12 per cent CO_2 there was only a slight yellow haze issuing from the stack. As the temperature of the gases leaving the economizer is only 121°C. (250°F.), and the percentage of heat lost in the stack gases less than 7 per cent, the loss due to excess air was more than offset by the gain in evaporation and the longer life of the furnace lining with the lower temperatures and CO_2.

This installation of four boilers is ordinarily served by two economizers, two induced draft fans and one stack. During the test the one boiler was taken off and the flue sealed so that no air or gas could go through the one economizer except that coming from the boiler being tested. Thus, during the test, the one fan and economizer were used exclusively for the test boiler. The tubes were blown once in every 12 hr. and the furnace cleared at the end of the four tests. The amount of ash taken out was proportioned between the four tests according to the ash percentage in the coal and the number of hours duration of each test. There was only a slight amount of dust in the flues and dust chamber at the end of the tests, and this was not weighed but counted in with the ashes blown away with the stack gases.

During No. 4 test it was noticed that the coal formed into small balls which fell burning onto the bottom of the furnace, while in the other tests the coal was completely consumed before reaching the bottom of the furnace. This trouble in the last test was caused by the quality of the coal used. The chemical analysis showed that the coal contained over 19 per cent of ash and it was evidently this foreign matter that had become heated that was seen dropping out of the bottom. Trouble was also found with this coal in making it run from the bunkers, as it would not run unless agitated.

The dimensions of the boilers are as follows:

Combustion space	2,000 cu. ft.
Water heating surface in boiler	5,201 sq. ft.
Water heating surface in economizer (ordinarily serves 2 boilers)	3,931 sq. ft.
Superheating surface	943 sq. ft.
Total heating surface of boiler	6,144 sq. ft.

During the period of regular operation pulverized anthracite was used for about two weeks, in June, 1920. This coal was dredged from the bed of the Susquehanna River at Harrisburg; the ash content was about 18 per cent and the calorific value about 12,000 B.t.u. This fuel gave excellent results and the company's engineers liked the combustion conditions even better than those obtained with high volatile coal. The flame was somewhat shorter and the temperature in the combustion chamber a little lower, while the sediment accumulating in the bottom of the chamber was in the nature of a powder which could readily be removed.

During the period when anthracite was used the pulverizing elements in the mills showed so much wear that the use of anthracite was discontinued temporarily and bituminous coal was substituted. These two kinds of pulverized fuel have been found to be readily interchangeable.

Since this difficulty was encountered the company has made an extensive investigation of available means for pulverizing anthracite and two methods are to be tried out: (1) Fuller-Lehigh mills are being fitted with specially chilled pushers and rings and with forged balls of chrome-nickel steel. (2) The installation of a tube mill is being considered. This will be equipped to operate with air separation and will be run in closed

TEST OF 520-HP. BOILER AT THE LEBANON PLANT OF THE BETHLEHEM STEEL CO.

Test No.	1	2	3	4
Coal:	Bit. Ocean Mine	Bit. W. Va.	Washed anthracite*	Bit. W. Va.
Proximate analysis:				
Moisture, per cent.	0.8	0.9	2.7	0.8
Volatile, per cent.	32.7	29.9	6.4	30.2
Fixed carbon	56.5	52.6	82.1	50.3
Ash, per cent.	10.8	17.5	11.5	19.5
Sulphur, per cent.	1.5	1.3	1.0	1.2
Fineness, per cent through 100 mesh		89.8		
Flue gas:				
CO_2, per cent.	7.6	8.3	7.2	7.7
O_2, per cent.	15.9	8.8	7.2	18.2
CO, per cent.	0.2	0.17	0.4	0.1
Dry coal per hour, pounds	2,067.0	2,247.0	2,503.0	2,615.0
Dry coal per cubic foot of furnace volume, pounds	1.03	1.12	1.25	1.3
Ash and refuse (dry):				
Removed from furnace and flues, pounds	1,380.0	2,328.0	74.0	1,443.0
Blown away with gas	3,992.0	6,727.0	190.0	4,167.0
Total	5,372.0	9,055.0	264.0	5,610.0
Combustible in ash retained	0.0	0.0	0.0	0.0
Duration of test	24 hr.	23 hr.	55 min.	11 hr.
Steam pressure by gage, pounds	92.7	87.7	85.0	83.2
Temperature degrees:				
Boiler feed water F.	155.6	166.0	157.0	165.0
C.	68.6	74.4	69.4	74.0
Gases, top of third pass, F.	458.0	474.0	457.0	500.0
C.	236.6	245.5	236.0	260.0
Gases leaving economizer, F.	248.0	252.0	246.0	252.0
C.	120.0	122.0	119.0	122.0
Efficiency, based on combustible, per cent.:				
Boiler and furnace	76.6	77.3	72.6	82.3
Boiler, furnace and economizer	82.7	84.3	78.5	85.8
Per cent of rated capacity	130.1	141.7	140.9	149.7

* Small sample prepared at Steelton plant.

circuit with an air separator. It is expected that either of these mills will operate well enough to warrant the use of anthracite in preference to bituminous coal.

These boilers have been operating on pulverized bituminous coal for nearly a year. As long as the furnace temperatures are kept sufficiently low by the use of excess air, the ash is deposited on the furnace bottom in a loose form which can be readily broken up by playing a stream of water upon it. The ash is allowed to accumulate for about two weeks, or until it is about 10 in. deep, and is removed when the boiler is shut down over a week end. When operating with low excess air and high furnace temperatures, the ash accumulated as a molten slag, which solidified in a hard mass which was difficult to remove (see also p. 690).

Comparison of Pulverized Coal and Stokers.—The high efficiency obtainable with modern stokers has rendered the introduction of pulverized fuel for boiler firing less attractive, at first sight, than in the case of industrial furnaces. The development of the underfeed stoker has forestalled pulverized fuel in this field so that the latter has a more difficult road to travel. Many engineers regard pulverized coal as the ideal fuel, but the additional machinery required for its preparation seems a handicap and renders it difficult to make the plant as compact. It is claimed, however, that large new plants can be equipped for the preparation and burning of pulverized fuel at less cost than for burning coal on stokers.

It should also be considered in cases where hand firing is to be superseded, or where old stoker equipment is to be replaced, and especially where low-grade coal is to be burned. Occasionally the capacity of an old plant may be increased by firing the existing boilers with pulverized coal, owing to limitations in the size of flues and stacks. The smaller amount of excess air required is then an important factor.

The elimination of clinker troubles is an important advantage when poor coal is being burned. Some old boilers are mounted so close together that there is no room to get in at the sides with a bar for breaking up clinkers, which is necessary when substituting underfeed stokers.

Mechanical stokers can handle much poorer grades of coal than can be burned satisfactorily by hand firing, and with less smoke. The underfeed types are capable of burning bituminous coal with considerable ash, especially if steam is injected upon

the clinkers which fall against the bridge wall and side walls, to prevent them from adhering to the bricks; but the output of the boiler is reduced in proportion to the leanness of the coal. Power operated ash dumps are also effective for handling large amounts of ash and for breaking up clinkers.

The percentage of combustible in the ash ranges from about 12 to over 40. In new installations, however, this loss can be reduced to something in the neighborhood of from 7 to 9 per cent by the use of clinker grinders.

A great many low-grade western or middle-western coals are free burning, as distinguished from caking coals, and can be burned successfully on stokers of the chain-grate type. Whatever the type of grate or stoker, however, the grate area for carrying a given maximum load must be proportional to the volume of the fuel, which varies inversely as the calorific value, roughly speaking

The maximum rate at which coal may be burned on stokers is approximately from 65 to 70 lbs. per square foot of grate area, and this limitation is independent of the grade of fuel used.

One considerable source of loss in stoker installations is from cinders carried up the stack. This may average about 2¼ per cent.* In some large central stations cinder catchers are installed to prevent their accumulation in the neighborhood. The gases are passed under a hanging wall located above a tank filled with water, and their direction of travel is sharply reversed. The Metropolitan cinder catcher is of this type.

The above limitations do not apply in the case of pulverized fuel. The furnace volume required for burning various grades of bituminous coal is substantially the same, regardless of the calorific value of the fuel, or of the percentage of ash. With any properly designed furnace the loss from combustible in the ash, or carried up the stack, is negligable.

Operation of a Central Station with Pulverized Coal.—Before carrying this comparison any further, it will be well to review the operation of the Oneida Street station of the Milwaukee Electric Railway and Light Co. One-half of the boilers are equipped for burning pulverized coal (pages 705 and 707), while the other half are equipped with a modern type of underfeed stoker. In Nov., 1919, the pulverized coal-fired boilers were given a 4-days test at their most economical rating.

* SCHEFFLER and BARNHURST, *Mech. Eng.*, Sept., **1919**, 755.

The data obtained are summarized in the following pages,* together with the observations and conclusions of John Anderson, chief engineer of power plants for the Milwaukee Co., and Paul Thompson, technical engineer of power plants for the Detroit Edison Company, who was present as an observer during the four days. Some of Anderson's introductory observations follow.

The cost per ton of preparing coal depends upon the size of the plant and the quantity of fuel handled, but ordinarily will vary between the limits of 25 and 50 cts.† It seems that a great deal of work toward reducing this cost remains to be done, especially along lines of utilizing waste gases for drying, in plants not provided with economizers. Development of a furnace design which will allow of burning a large percentage of finely divided coal, but capable of taking care of a smaller amount of larger sized particles, presents further study along this line. This is possible in view of the fact that the pulverizers consume about 86 per cent of the total electric energy required for all moving parts of the coal preparation equipment. Both of the items mentioned above, if capable of being reduced as suggested, will also cause a reduction in the cost of the pulverizing department labor.

Continuous and uniform operation of the pulverizing division of a plant is dependent largely upon the ability of the operators to recognize and meet the varying properties of the coal as it arrives. Dryer operation especially must be changed frequently so as to handle varying sizes of coal (from high percentages of dust to high percentages of small nut) and varying amounts of moisture, both inherent and surface, and yet supply continuously a coal of uniformly low moisture. Irregularities in the drying process usually manifest themselves throughout the entire coal cycle, and very often with the result that the fuel feeding system becomes plugged at points most readily affected by wet coal. Air, additional to that used for carrying the fuel into the furnace, is taken through auxiliary inlets, located in the furnace front, and can be varied in amount by manipulation of the stack damper, which serves to change the gas velocities through the boiler and thus the volume taken into the furnace. With coal and air supplies easily adjustable, perfect fire control is assured and it becomes at once obvious why coal is burned so efficiently in pulverized form.

The condition desirable is that, with the percentage of CO_2 as high as practicable, there should be no CO—a condition obtainable to a greater

* From "Use of Pulverized Coal Under Central Station Boilers," by JOHN ANDERSON, presented before the Technical League of the Employes' Mutual Benefit Association, Milwaukee, February 19, 1920.

† These figures, apparently, do not include fixed charges on the investment.

degree in a pulverized fuel furnace than in any other type. Complete combustion with the least amount of excess air requires the best distribution of that air and the problem of furnace efficiency therefore resolves itself mainly into one of air supply, not to the furnace alone, but to each particle of coal. With a fuel finely pulverized, air can be made at once available to each particle, since the surface exposed to air is increased many times that of a lump and combustion is rapid, complete and efficient. With fuel in lump form, air must be supplied through a bed, the outer surface of the lumps must be burned off, the process of combustion eating into the lumps slowly, and as a result combustion is often gradual and unequal—where the fire is thin too much air is passed; where it is heavy there is too little air. To insure complete combustion in any furnace, some excess air must therefore be provided. The use of pulverized fuel reduces this excess to a minimum, gives a higher and more uniform percentage of CO_2, and therefore a higher and more uniform efficiency.

The percentage of CO_2 to be maintained in pulverized fuel practice is determined to a great degree by furnace limitations, rather than combustion considerations. From 16 to 17 per cent CO_2 in the flue gases is easily obtainable, but it cannot be maintained in actual operation, due to exceedingly high flame temperatures that result and the consequent destruction of the brick work. The temperature of the furnace therefore must be regulated by varying the volume of excess air. The temperature of the flame should not be above 1,650°C. (3,000°F.) and that of the brick work in the flame zone not more than 1,300 or 1,370°C. (2,400 or 2,500°F.). Higher temperatures than these usually result in fusion of the ash particles and formation of a molten slag which is very destructive to the brick work with which it comes in contact.

In attempting to carry combustion conditions of a furnace so as to obtain exceedingly high percentages of CO_2, usually too little attention is given to the losses resulting from the formation of carbon monoxide, or CO. Carbon monoxide, a highly combustible gas, is formed when the excess air admitted to the furnace is insufficient to properly surround and completely oxidize all the coal particles. Heat losses occurring when carbon monoxide is present in the gases of combustion, outweigh any gains that may be effected by an exceedingly high CO_2 and are always to be avoided.

In the discussion of furnace efficiencies consideration should be given to the adaptability of a pulverized fuel fired furnace to the use of widely varying grades of coal without resultant losses in economy. Further, boiler capacity, even under heavy overloads, is in no way affected when an inferior quality of coal is burned. It is known that the combined efficiency of a boiler and furnace does not decrease when the fuel is poor,

which condition does not hold true for the stoker. In the case of the stoker, the dropping off in efficiency is at a more rapid rate than the B.t.u. value of the fuel would indicate as normal, and so much so that the point is rapidly reached when proper combustion cannot be maintained.

Operation of a pulverized fuel fired boiler, equipped with proper instruments, can be varied to take big fluctuations in load over very brief periods of time. A heavy overload can be quickly taken on or dropped off by adjustment of the coal and air feeds, and without any waste of fuel as always occurs under like conditions in stoker practice. No losses occur due to clinkering of coal or cleaning of fires, this condition of operation being entirely eliminated. Irregularities caused by change in quality and variation in size of coal, such as the fireman cannot successfully cope with on stokers, are also eliminated. Furnace conditions necessary to most economical combustion are more perfectly obtained and hence a horizontal combined efficiency curve is possible of approximate attainment.

Due to its easily regulated coal and air supply and its perfectly controlled rate of combustion, the pulverized fuel furnace practically eliminates losses of combustible in ash. Ordinarily this loss is relatively large and varies according to the nature of the coal, type of stoker and the boiler load carried. In pulverized fuel practice the loss is very small and these variations do not occur.

The ease with which the fuel feed and draft are controlled, the ability to take on and drop off heavy overloads in a brief time, the thorough combustion of the coal and the uniformly high efficiency obtainable under normal operation, constitute the chief advantages of pulverized fuel over other methods of coal burning.

An additional economy is effected during banked boiler hours. Banking conditions when operating with pulverized fuel are somewhat different than those obtained in stoker practice. By stopping the fuel supply and closing up all dampers and auxiliary air inlets, a boiler fitted for use of pulverized fuel can be held up to pressure for several hours. The furnace brickwork having been heated to incandescence during operation gives off a radiant heat which is almost all absorbed by the boiler rather than escaping up the stack intermixed with an excess of cooling air. Radiation losses only occur, as against radiation plus stack and grate losses in the case of the stoker.

Commenting for a moment on the maintenance features of such a plant as has been described, it is the writer's belief, based on 2 years, operating experience, that the furnace brickwork in a pulverized fuel furnace will stand up equally as well as a stoker installation, with a very great advantage in favor of the former, due to the elimination of all iron work in the furnace or anywhere near the high temperature zones of the

boiler furnace. Regarding the maintenance of the pulverizing plant equipment, it has not been found that any great amount of maintenance is likely to be necessary, as all the equipment is of the slow moving type and many opportunities are afforded of applying the same concentration of effort that has been typical of the stationary engineer's work in improving equipment when defects or fast wearing parts are uncovered. The pulverizing machinery manufacturers have done a great deal along this line, but there are still matters that can be improved upon by the engineer looking for the least troublesome as well as most economical plant from a maintenance standpoint.

Powdered fuel installations are not feasible in every location. There is one limitation and that is the size of boiler plant to be served. A plant of less than 2,500 developed boiler hp. on a 24-hr. operating basis should not consider using powdered fuel. The amount of coal pulverized per day, the cost of installation, and the labor for operating the preparation plant, when properly studied, will bring before those interested the reasons therefor.

In general, we have found the powdered fuel method applied to our furnaces a distinctly advantageous one. Our firemen prefer to operate such equipment rather than the stokers when it becomes a matter of choice. It has proved more economical, as evidenced by the monthly coal bill. It seems to make the formation of scale in the boiler less than in stoker-fired boilers. There is absolutely no trouble from smoke; consequently no reduction in ability of boiler to absorb heat due to soot on tubes.

The use of high-sulphur coal, which is so destructive to boiler tubes, breechings, smokestack, and all other steel equipment found in a boiler plant, is much more satisfactory, as the low moisture content of coal as fired reduces the opportunity for attack from sulphuric acid.

Although frequently cautioned against explosions, we have had no evidence that such caution is necessary. The reason for our freedom from such unpleasant occurrences is due almost entirely to a proper care in preventing coal from being dried too much and pulverized to a fineness beyond what is necessary. Matters of this kind are in the hands of the operating engineers and do not benefit by the application of theories. The engineer who is careful of his every-day equipment and keeps his plant free from accidents of every nature, from flywheel explosion to burned out motors, can operate a pulverized fuel plant successfully without other assistance than his own experience.

An actual comparison of results obtained with pulverized fuel and with a stoker-fired furnace has been derived from tests conducted on both at the Oneida Street plant and are included in the following report.

Report On Test Of Five 468-hp. Boilers Equipped With Pulverized Fuel Burning Furnaces—Oneida Street Power Plant

November 11–15, 1919

Equipment.—Screenings coal is delivered to the station by barge and run over an automatic scale, discharged onto a short belt conveyor equipped with magnetic separator pulley for removal of tramp iron, and then into a Peck carrier, which carries it to the green coal storage bunkers, the starting point. From there it is conveyed and elevated to a Jeffrey disintegrator, where it is prepared for drying by being crushed, discharged into a small storage bin and fed to the dryer. The dryer is of a double-shell type, and is so arranged that the gases exhausted from it are discharged through a cyclone separator, where coal dust, carried from the shell, is reclaimed and conveyed to the pulverizers. The gases discharged from the separator are vented into the smokestack. The dried coal is carried from the dryer discharge by a bucket elevator to the dry coal storage bins, to which are connected the pulverizer feeders. The pulverizers are of the five-roll Raymond type. Pulverized coal from the mill outlets is conveyed by screw conveyors to the pulverized fuel storage bins. Screw feeders take the fuel to the air-mixing chamber, from where it is blown to the furnaces.

Operating Conditions

Pulverizing Room.—Operation in the pulverizing room was changed somewhat during the test in order to fulfill conditions required in making the periodic checks of boiler operation. It was essential that the levels of the fuel in the pulverized bins should be controllable at certain hours of the day (at the time of check) and therefore operation of pulverizer equipment was extended over 24 hr., although, without these considerations, sufficient coal could have been pulverized during the 18-hr. run. As a result, irregular operation of the equipment—frequent starts and short runs—increased power consumption and decreased hourly capacities.

No interruptions, due to failure of equipment, occurred during the test. The pulverized fuel conveyor choked up on two occasions when the storage bins were allowed to overfill at a check hour.

Uniform and satisfactory removal of moisture was affected by the dryer without any unusual regulation. The firing of the furnace was varied, as it is ordinarily, depending upon the moisture content of the green coal. The pulverizers operated uninterruptedly and provided fuel of the desired fineness with little variation.

Pulverized Fuel Storage Bins

During the first 24 hr. of the test, it appeared that moisture, with its attendant difficulties, was collecting in the storage bins. Cold air draughts through windows alongside of the bins caused this condition by rapidly condensing the vapor in the entrained air. When the windows were tightly closed, it was eliminated.

BOILER ROOM

A high percentage of CO_2 was easily obtainable, but could not be maintained for longer than an hour at a time, due to excessive slagging on the hearth. This slagging on the hearth and furnace bottoms may be attributed to flame characteristics resulting from certain draft conditions and can only be avoided by air regulation. On the newer type of Lopulco furnaces, like those in use at the Oneida Street plant, the method of air regulation is such that, while admitting air for slag prevention, a large volume not needed for combustion enters, by-passes the flame zone and is carried with the products of combustion in the form of excess air. The high percentage of excess air, together with a correspondingly low percentage of CO_2, as indicated by the flue gas analysis, was not determined by combustion considerations but rather by furnace limitations.

No slagging occurred on the boiler tubes.

Flues were blown once every 8 hr.

Slag was withdrawn from the furnaces twice in 24 hr.

Back chamber ash was removed once every 2 days.

Due to the use of a single stack for the entire boiler plant, which includes six underfeed stoker boilers, no smoke observations were made. Smoke from the pulverized coal furnaces, however, has proved to be of a negligible quantity on all occasions when pulverized fuel alone is used and appears in the form of a light-yellow haze, which disappears within 25 yd. of the stack. The ash particles are so fine that no estimate can be made of the distance they are carried before being dropped from the air. No noticeable deposit has accumulated on or about the plant, although continuous operation has been carried on for more than a year.

T. M. E. R. U. L. & Co., TEST OF FIVE 468-HP. BOILERS—
NOS 1 TO 5, INCLUSIVE
ONEIDA STREET POWER PLANT
November 11–15, 1919

DIMENSIONS	
1. Number and kind of boilers	Five Edge Moor water tube boilers
2. Kind of furnaces	Pulverized fuel burning furnaces
3. Volume of combustion space, per boiler, cubic feet	1,678
4. Water heating surface, square feet per boiler	4,680
5. Superheating surface, square feet per boiler (approximate)	594
(a) Type of superheater	Foster
6. Total heating surface, square feet per boiler	5,274
(a) Ratio of water heating surface to volume of combustion space	1 to 0.359
(b) Ratio to total heating surface to volume of combustion space	1 to 0.318
DATE, DURATION, ETC.	
7. Date	Nov 11–15, 1919
8. Duration, hours	99
(a) Boiler hours	495
9. Kind and size of coal: Mixture: 50 per cent Yough. scrgs.; 50 per cent Eastern Kentucky scrgs.	

AVERAGE PRESSURE, TEMPERATURES, ETC.

10. Steam pressure by gage, pounds per square inch	167.8	
(*a*) Barometric pressure, inches of mercury	29.49	
11. Steam pressure, absolute, pounds per square inch	182.3	
12. Temperature of steam leaving superheaters, degrees Fahrenheit	441.9	(228°C.)
(*a*) Normal temperature saturated at above pressure, degrees Fahrenheit	374.2	(206°C.)
13. Temperatures of feed water entering boiler, degrees Fahrenheit	156.3	(69°C.)
14. Temperature of escaping gases, degrees Fahrenheit	496.6	(258°C.)
(*a*) Temperature of flame above hearth, degrees Fahrenheit	2,767	(1,520°C.)
(*b*) Temperature of furnace bottoms, degrees Fahrenheit	2,180	(1,180°C.)
15. Draft under damper, inches of water	0.173	
16. Draft in furnaces, inches of water	0.031	

QUALITY OF STEAM

19. Number of degrees of superheat	67.7	(37°C.)
36. Percentage of rated capacity developed	118.4	

GROSS EFFICIENCIES

45. Calorific value of 1 pound of dry coal by calorimeter, B.t.u.	12,810
46. Gross efficiency of boiler and furnace, per cent	80.67
47. Efficiency of furnace, per cent	99.79

ANALYSIS OF FLUE GASES

49. Carbon dioxide, per cent	12.26
50. Oxygen, per cent	6.82
51. Carbon monoxide, per cent	0.00

ANALYSIS OF COAL

	As Received	As Fired	Dry
52. Proximate.			
(*a*) Moisture	7.23	0.67	
(*b*) Volatile	32.13	34.40	34.63
(*c*) Fixed carbon	49.60	53.11	53.47
(*d*) Ash	11.04	11.82	11.90
	100.00	100.00	100.00
(*e*) Sulphur separately determined, referred to dry coal			1.62
53. Ultimate analysis.			
(*a*) Carbon			73.57
(*b*) Hydrogen			4.35
(*c*) Oxygen			7.22
(*d*) Nitrogen			1.34
(*e*) Sulphur			1.62
(*f*) Ash			11.90
			100.00

54. Analyses of—

	Slag	Combustion Ash Retained	Combustion Ash Lost
(*a*) Moisture	0.00	13.00	
(*b*) Combustible	0.59	13.76	Unknown
(*c*) Earthy matter	99.41	86.24	

Analysis of Losses as Shown by Heat Balance

Losses Due to Evaporation of Moisture in Coal.—These losses, when expressed in a heat balance, are dependent upon the quantity of moisture in the coal as fired, and ordinarily are independent of installation. Since, in this case, the coal was dried to 0.67 of 1 per cent of moisture, only a small loss, 0.06 of 1 per cent, due to the presence of moisture, occurred in combustion. The actual loss resulting from this factor is set forth in the table showing net boiler efficiency. It exceeds the minimum theoretical loss, dependent upon quantity of moisture that is always assumed in a heat balance and which in this case would be (if coal had not been dried) equal to 0.6 per cent. The efficiency of the dryer referred to this basis is but 40 per cent.

Losses Due to Heat Carried Away in the Dry Flue Gases.—In view of the fact that the boilers were operated at the most economical rating, these losses were higher than expected. To account for them, it must be considered that, up to the time of the test, three of the five boilers had been operated about 300 hr. since receiving a partial wash, and that each of the five had been in service 600 hr. since the last full cleaning. This condition, together with the fact that 90 per cent of the feed water was untreated, reduced the heat absorption of the boilers appreciably. One of the boilers examined subsequent to the test showed scale deposits sufficient to affect efficiency.

Further losses under this heading may be attributed to an excess of air, not needed for proper combustion, but essential to the control of furnace temperatures and the prevention of excessive slagging on the hearth and furnace bottoms.

Losses Due to Carbon Monoxide.—These were not measurable, since but few gas analyses showed CO present, and then only in traces.

Losses Due to Combustible in Ash.—This loss is very small and denotes the completeness of combustion. Since but 17.2 per cent of the total ash (laboratory basis) was recovered and half of that—the slag—contained no combustible, it might be assumed that, with the 82.8 per cent of ash that escaped with the flue gases, a large amount of combustible was carried away. On the other hand, it is more likely that, since the unaccounted for losses are less than in the average boiler test, most of the unburned combustible lodged in the combustion chamber, and were without doubt the heavier particles.

Test on Fuel Pulverizing Equipment, Oneida Street Power Plant December 11–15, 1919

General Conditions—Average Temperatures, Etc.

1.	Temperature of air entering dryer furnace, degrees Fahrenheit	93.8 (34°C.)
2.	Temperature of gases leaving dryer, degrees Fahrenheit	181.8 (83°C.)
3.	Humidity of outside air, per cent	72.0
4.	Draft through dryer, inches of water	0.77
	No. 1 No. 2	
5.	Vacuum in pulverizers, inches of water. 5.0 5.16 Avg.	5.08
6.	Temperature of coal entering dryer, degrees Fahrenheit	88.2 (31°C.)
7.	Temperature of coal leaving dryer, degrees Fahrenheit	237.9 (114°C.)
8.	Temperature of coal leaving pulverizers, degrees Fahrenheit	169.7 (76°C.)
9.	Moisture of coal entering dryer, per cent	5.59
10.	Moisture of coal leaving dryer, per cent	1.61
11.	Moisture of coal leaving pulverizers, per cent	1.03
12.	Fineness of pulverized coal, 200-mesh, per cent	81.30
13.	Fineness of pulverized coal, 100-mesh, per cent	97.40
14.	Fineness of pulverized coal, 80-mesh, per cent	99.30
15.	Fineness of pulverized coal, 60-mesh, per cent	100.00

Total and Hourly Quantities

Crusher

16.	Total coal crushed, as received at crusher, tons	479
17.	Coal crushed per hour, as received, tons	17.5

Dryer

18.	Total coal dried, as received at dryer, tons	471.2
19.	Total coal dried per hour of dryer operation, as received, tons	6.7

Pulverizer

20.	Total coal pulverized, coal from dryer, tons	447.4
21.	Capacity of pulverizer per hour, tons	5
22.	Coal pulverized per hour, dry, tons, total	7.90
23.	Coal pulverized per hour, dry, tons, per mill	3.95
24.	Coal pulverized per hour, per mill, as received at plant, tons	4.23

Consumption of Lubricants

24.	Total grease consumed by elevators and conveyors, pounds	6
25.	Grease per ton of coal, as received, pounds	0.012
26.	Total grease consumed by pulverizers, pounds	13
27.	Grease consumed per pulverizer per hour of operation, pounds	0.112
28.	Grease consumed per pulverizer per ton of coal pulverized, pounds	0.028
29.	Grease consumed on all equipment per ton of coal, as received, pounds	0.040
30.	Total oil consumed on all equipment, quarts	17
31.	Oil consumed per ton of coal as received, quarts	0.036

ELECTRIC ENERGY AND COAL CONSUMPTION

32. Total energy consumed by crusher and green coal elevator		220
33. Energy per ton of coal, as received, kw.-hr.		0.47
34. Total energy consumed by dryer, kw.-hr.		735
35. Energy per ton of coal, as received, consumed by dryer		1.53
36. Total energy consumed by pulverizers, kw.-hr. (fan and drive motor)		8,010
	MILL No.1	MILL No. 2
37. Motor input per hour, hp	93.8	90.2
38. Energy consumed by pulverizer per ton of coal, as received, kw.-hr.		16.72
39. Energy consumed by pulverizer per ton of coal, as pulverized, kw.-hr.		17.90
40. Total energy consumed by pulverized coal conveyors, feeder blowers and feeders		1,789
41. Total energy consumed by pulverized coal conveyors, feeder blowers and feeders per ton of coal as received		3.73
42. Total energy consumed by pulverized coal conveyors, feeder blowers and feeders per ton of coal as fired		4
43. Total energy consumed by all equipment on preparation and firing of pulverized fuel, kw.-hr.		10,754
44. Energy per ton of coal, as received, kw.-hr.—grand total		22.45
45. Coal equivalent for this energy at 1.5 lb. coal per kw.-hr., pounds		33.68
46. Total coal used in dryer furnace		12,291
47. Coal per ton of fuel dried, pounds (based on coal as received)		25.66
48. Total coal and equivalent consumed in preparation and firing of 1 ton of pulverized fuel, pounds		59.34

COST OF PREPARATION—OPERATION AND MAINTENANCE

49. Cost of labor per ton of coal—operation	$0.143
50. Cost of fuel for drying plus fuel for electric energy—coal at $4 per ton	0.119
51. Cost of lubricants per ton of coal—grease at 9 cts. per pound	0.007
52. Cost of labor per ton of coal—maintenance	0.036
53. Cost of material—maintenance	0.020
54. Total cost per ton of coal	0.325

NOTE.—Item 49 is based on the labor required to pulverize coal sufficient for five boilers through a 24-hr. run per day.

SUMMARY SHEET

ELECTRIC ENERGY AND FUEL CONSUMPTION PER TON OF COAL PULVERIZED

1. Energy consumed by conveyors, crushers, elevators, dryer, blowers and feeders, kw.-hr.	5.73
2. Energy consumed by pulverizer, kw.-hr.	16.72
3. Total energy, kw.-hr.	22.45
4. Coal equivalent at 1.5 lb. per kw.-hr., pounds	33.68

5. Coal consumed in dryer furnace, pounds per ton of fuel dried..	25.66
6. Total coal and equivalent, pounds.....	59.34
7. Gross efficiency less deductions for total coal and equivalent—Item 6.....	78.36

COST OF FUEL PREPARATION, FIRING AND ASH DISPOSAL

8. Labor—coal preparation.....	$0.143
9. Labor—firing.....	0.121
10. Labor—ash removal.....	0.025
11. Dryer fuel—coal at $4 per ton.....	0.051
12. Electric energy—coal per kw.-hr. at 1.5 lb.....	0.068
13. Maintenance (labor at 3.6 cts.—material at 2 cts., manufacturer's estimate—lubricants at 0.7 cts.).....	0.063
14. Total cost of fuel preparation, firing, ash disposal and maintenance.....	0.462
15. Price of coal as purchased, per ton.....	4.000
16. Total cost.....	4.462

EFFICIENCIES

17. Actual gross efficiency, per cent.....	80.67
18. Net efficiency after all incidental costs have been accounted for, per cent.....	72.32

CONCLUSIONS

The conclusions can be best drawn from a comparison between pulverized fuel burning equipment and mechanical stokers.

COMPARISON OF COSTS AND NET EFFICIENCIES

ELECTRIC ENERGY AND FUEL CONSUMPTION PER TON OF COAL BURNED

	PULV. FUEL SYSTEM		MODERN STOKER
Energy consumed by conveyors, crusher, elevators, dryers, fans and feeders, kw.-hr.....	5.73	Stokers and blowers, kw.-hr.	10.94
Energy consumed by pulverizer, kw.-hr.	16.72		
Total energy, kw.-hr.....	22.45		10.94
Coal equivalent at 1.5 lb. per kw.-hr., pounds.....	33.68		16.41
Coal consumed in dryer furnace, pounds.	25.66		
Total coal and equivalent, pounds.....	59.34		16.41

COST OF FUEL PREPARATION, FIRING AND ASH DISPOSAL

Labor—coal preparation.....	$0.143		$0.000
Labor—firing.....	0.112		0.140
Labor—ash removal (in plant).....	0.025		0.064
Dryer fuel—coal at $4 per ton.....	0.051		0.000
Electric energy—coal per kw.-hr. at 1.5 lb.....	0.068		0.033

Maintenance:			
Labor at $0.036—material at $0.020		Labor at $0.046	
Manufacturer's estimate—lubricants at $0.007		Material at $0.049	
		Lubricants at $0.002	0.007
Total cost of fuel preparation, firing, ash disposal and maintenance	0.063		0.334
	0.462		
Price of coal as purchased, per ton	4.000		4.000
Total cost, per ton	4.462		4.334
Cost per ton of coal in P. F. system over modern stoker	0.128		
EFFICIENCY			
Actual gross efficiency, per cent	80.67		76.80
Net efficiency after all incidental costs have been accounted for, per cent	72.32		70.88
Difference in favor of pulverized fuel system, per cent	1.44		

The tests were conducted by the engineers of the T. M. E. R. V L. Co., being directly supervised by Fred Dornbrook, assisted by Schubert and Mistele, Test Engineers.

Paul Thompson, Technical Engineer of Power Plants, Detroit Edison Company, was present throughout the 4 days, as an observer.

R. H. MISTELE,
Test Engineer.

W. E. SCHUBERT,
Test Engineer.

FRED DORNBROOK,
Supt. of Power Plant Operation.

Observer:
PAUL W. THOMPSON,
Technical Engineer of Power Plants,
Detroit Edison Co.

Approved:
JOHN ANDERSON,
Chief Engineer of Power Plants.

PULVERIZED FUEL IN THE ONEIDA STREET PLANT OF THE T. M. E. R. & L. CO.

BY PAUL W. THOMPSON,

TECHNICAL ENGINEER OF POWER PLANTS, DETROIT EDISON CO.

There is at the present time a considerable difference in opinion among engineers as to the feasibility of burning pulverized coal in central generating stations, and as to whether, taking all facts into consideration, the use of pulverized fuel will result in a net saving over the results obtained with modern stoker installations. It is to be presumed that a general comparison of

any two plants, one equipped with stokers and one equipped for the preparation and burning of pulverized fuel, would probably not give results which would be readily comparable in determining the ultimate relative value of one method of burning fuel over the other because of the probable different conditions of operation and the difference in design, kind and cost of fuel, cost of labor, etc.

In order to determine the feasibility of burning pulverized fuel, the Milwaukee Electric Railway & Light Co., early in 1918, decided upon a trial installation on one of the 468-hp. boilers in the Oneida St. Power Plant. The necessary equipment was installed, and, after preliminary operation and making certain changes which were found to be necessary, they found the installation to be entirely successful; so the remaining four boilers in the south end of the plant were equipped for burning pulverized fuel. By so doing they now have five 468-hp. boilers under which the pulverized-fuel system has been installed. This is practically one-half the boiler capacity of the Oneida Street Plant and is a sufficiently large installation to compare directly with the other boilers in this station having Riley stokers, or similar boilers in the Commerce Street Station also equipped with Riley stokers, which are subjected to practically the same operating conditions as are the boilers under which the pulverized fuel is burned.

In order to obtain data on the pulverized fuel installation, for the purpose of comparing it with their stoker installation and determining the relative advantages, the Milwaukee Electric Railway & Light Co. conducted a test on the pulverizing equipment and boilers under which this fuel was burned, at which test the writer was present as an observer. The five boilers mentioned above were operated at as nearly a constant rating as possible of 120 per cent for a period of 4 days from November 11 to 15, inclusive. Throughout the duration of the test data were taken from which the overall efficiency of boilers and furnaces was computed and also attention was paid to the operating labor cost. It is unnecessary to go into the details of the test or methods employed, as these will be found in the final report of the test. It is sufficient to say that the test was properly conducted and particular care exercised in obtaining an accurate record of all quantities involved. The water and coal were weighed and the scale checked for accuracy at frequent intervals. All

blowoff piping was disconnected from the boilers to preclude any possibility of error due to leakage. The boilers were subjected to regular normal operation, except that the rating was held at practically a constant figure, and no special effort was made to obtain an efficiency which would not be obtained under normal plant operation.

During the test the author availed himself of the opportunity of watching carefully the boiler room operation and also the operation of the pulverizing, drying, and coal-handling equipment, and was very favorably impressed with the installation from an operating viewpoint.

The boiler room operation was indeed much simpler than is obtained with a stoker installation. The rate of steaming of the boiler is controlled by varying the speed of the feeder motor and adjusting the damper to take care of the different quantity of flue gas. It is unnecessary to look into the furnace at any frequent interval, as is the case when firing with stokers and where holes in the fire or heavy spots must be corrected. In fact, when once the feeder speed is set to give a certain rate of steaming of the boiler, there seems to be no reason why this rating could not be maintained continuously as far as the furnace is concerned without it being necessary to make any changes whatever. Variations in the kind and quality of fuel burned seemed to have no effect on the operation, except that, when feeding at a constant quantity, the rating of the boiler varied with the heating value of the coal. At one time during the test Youghiogheny was used, which coal had a higher heating value, higher volatile content, less ash and less sulphur than the mixture of Youghiogheny and Kentucky coal which was used throughout the remainder of the test.

Losses which are inherent in stoker practice, such as breakdowns in the stoker itself, breaking up clinkers, loosening clinkers, continually watching the fire to maintain correct and uniform thickness, watching the gas passes of the boiler to see that no large sparks which indicate a carrying away of combustible, dumping, and the many other operations that are necessary in stoker operation, are eliminated. In other words, efficient combustion is obtained at all times without continual supervision by an experienced operator and from the standpoint of reliability of operation the odds are in favor of the pulverized fuel. This is an item for serious consideration in plants designed with 4.5

kw. capacity or more per installed boiler horsepower, where the losing of a boiler due to stoker trouble at the time of maximum load on the station might seriously overload the remaining boilers or make it necessary to drop a portion of the load on the plant.

The handling of the ash resulting from combustion of the pulverized fuel is a very simple matter, due to the very small quantity which is deposited in the furnace. It is in the form of a very fine impalpable powder, which, during the test, was removed twice each 24 hr. On several occasions during the first and second day of the test, slagging occurred in a furnace due to not admitting a sufficient quantity of air. The direct cause of this was the over-anxiousness on the part of the men conducting the test, to obtain, a higher percentage of CO_2 in the flue gas, and the reduction in the excess air permitted the furnace temperature to rise to a point where slagging occurred. The removing of this slag from the bottom or floor of the furnace, presented more difficulty than is usually experienced in removing the refuse from the ash hopper of a stoker-fired boiler. This slag had to be broken up and pulled out before it fused to the brick lining of the furnace. It appeared to the writer that this formation of slag could have been almost entirely eliminated by a more frequent inspection of the floor of the furnace and the admitting of more air through the openings in the front of the furnace, if it was found that slag was beginning to form. Even at times of removing this slag, it was possible to maintain the rating on the boiler by increasing the coal feed, which, however, resulted in a decreased efficiency during this time, amounting to about forty-five minutes in 24 hr. for each boiler. A large portion of the ash resulting from combustion is carried on through the passes of the boiler and out of the stack. Owing to the fineness of this ash, it apparently carried a considerable distance, even in a moderate wind, before being precipitated. Throughout the test there was a moderate wind blowing probably between 4 and 8 miles per hour, and the writer was unable to find any noticeable deposit in the streets. Even at the time of blowing the deposit of ash from the boiler tubes, which was done three times a day, requiring about 20 min. per boiler for each blow, no noticeable precipitation of ash could be found in the streets. At no time during the test was there any tendency for slag to form on the tubes of the boiler.

Strictly speaking, there is no such thing as a banked boiler when using pulverized fuel, as all that is necessary when it is desired to cut out a boiler is to shut off the coal feed and close all the dampers and auxiliary air inlets to the furnace. In this way the Milwaukee Electric Railway & Light Company has found by test that it is possible to hold the boiler to pressure for about ten hours by the radiant heat stored in the furnace and boiler setting which is gradually absorbed by the boiler. The loss which occurs, and which can be compared to the banking loss in a stoker-fired boiler, is the heat which is radiated from the boiler and setting and is equivalent to the amount required to reheat the boiler and setting to the temperature attained when steaming. In a plant where the ratio of boiler banking hours to boiler steaming hours averages 43 per cent or greater, which corresponds to an average daily plant load factor of 67 per cent, the saving resulting from the use of pulverized fuel is worth considering. Assuming 0.2 lb. coal consumed per b.hp. banking hour in a plant equipped with underfeed stokers, this loss amounts to about 1.5 per cent, which, in a pulverized fuel burning plant, should easily be reduced to one-half this figure, resulting in a net saving of 0.7 per cent on this item alone.

The conveying and preparation of pulverized fuel presents a somewhat more complex problem, although the present equipment in the Oneida Street station is operating satisfactorily, and, during the test, operated without any serious interruptions. Moisture in the pulverized fuel, caused by sweating on the inside of the pulverized fuel bins, resulted in some feeder troubles. This, however, was only a temporary condition and was overcome by closing the windows above the bins, thus stopping the cold air from blowing directly on them. One of the feeder pipes between the bin and the furnace became partially plugged, due to a paper composition gasket becoming lodged in the pipe just above the burner. The boiler on which this occurred was operated for at least 24 hr. at the desired rating by increasing the feeder speed on the other burner until the trouble was located and removed. During this period the efficiency of combustion was undoubtedly below the average as the coal which did come through the plugged feeder was not fed in with the correct quantity of air due to the obstruction in the feeder pipe. No trouble was experienced with the dryer or pulverizing mills at any time during the test.

The author does not believe that, under test conditions over a period of constant boiler rating, the efficiency obtained with the use of pulverized fuel will exceed that which has been obtained from the best stoker practice under similar operating conditions. However, under normal operation it is believed that the elimination of the many variable conditions entering into stoker operation will result in higher efficiency for the pulverized fuel installation. Overall efficiencies of boiler, furnace, and grate as high as 82 or 83 per cent have been obtained on test with stoker-fired boilers, but normal operation, day in and day out, seldom exceeds 76 per cent in the very best practice where highly skilled help is employed in supervising the boiler room operation. The gross overall efficiency of boiler and furnace of 79.6 per cent, as obtained from the results of this test, would unquestionably have been higher had the boiler been cleaned prior to the test. As a matter of fact, each boiler had been in operation prior to the test approximately 600 hr. since being entirely cleaned, including approximately 300 hr. on three of the boilers since cleaning the first four rows.

Inasmuch as the boiler feed water consists of approximately 90 per cent untreated water, the scale formation in the tubes would tend to give a lower efficiency than would have been obtained with clean boilers.

Certainly the results obtained in the pulverized fuel burning plant as a whole, where the equipment was installed and made to fit into an old plant originally equipped with Jones stokers, are encouraging enough to warrant serious consideration of the use of this kind of fuel in stations to be built in the future. There are many improvements which can be made in the design of a new plant, especially in the design of furnace, location of drying and coal pulverizing equipment, method of coal handling, drying and pulverizing, method of ash handling, slag prevention, possibility of using waste gases for the drying of fuel, all of which will have an effect on the efficiency which may ultimately be obtained. The application of pulverized fuel to central generating stations has been in use to a very limited extent for several years, but there still remains much experimental work to be done before we can hope to exhaust all the possibilities for increased efficiency, and bring it to as high a state of development as is the stoker at the present time.

LATER SERIES OF TESTS AT THE ONEIDA STREET STATION, MILWAUKEE, WITH ILLINOIS COAL*

By Henry Kreisinger and John Blizard

This section gives the summary of the results of a series of 11 tests made on a 468 hp. Edgemoor boiler equipped with a Foster superheater and fired with pulverized coal, at the Oneida Street Station of The Milwaukee Electric Railway and Light Co., Milwaukee, Wis. The tests were made by the Fuel Section of the U. S. Bureau of Mines in cooperation with the Research Department of the Combustion Engineering Corp. The powdered coal equipment was designed and installed by the Pulverized Fuel Equipment Co. The coal burned in these tests came from the Illinois coal field. The object of the tests was to determine what overall efficiency can be obtained with pulverized Illinois coal under various conditions of furnace operation and different preparation of coal as to degree of fineness and percentage of moisture.

The tests were made in a thorough manner, everything being done to make the results accurate and reliable. The pulverized coal was weighed in specially designed tanks placed on platform scales as it was supplied to the furnace. The tests were of 17 to 25 hours' duration.

Tests 28 to 30, inclusive, were made with the usual preparation of coal as it is burned in the plant under ordinary operating conditions. Test 31 was made with the same condition of coal as in the three previous tests, but with the furnace provided with a cooling coil over the hearth and along the walls near the bottom of the furnace to facilitate the removal of ash. Tests 32 to 35, inclusive, were made with the same furnace arrangement as test 31, but with the coal pulverized to a lesser degree of fineness. Tests 36 to 38, inclusive, were made with the same furnace arrangement as in the previous four tests, but with undried coal.

The cooling coil consisted of three lengths of 2-in. pipe over the hearth and two lengths along the side walls and the rear wall. The total surface of the coil was 48 sq. ft.

The coal weighing apparatus was placed between the storage bin and the feed bin. There were two burners and two feeders, and the coal to each feeder was weighed separately. The

* From a paper presented at the Spring Meeting, Chicago, Ill., May 23 to 26, 1921, of the American Society of Mechanical Engineers, entitled "Boiler Tests with Pulverized Coal."

weighing tanks were connected to the storage bins and the feeder bin by flexible canvas connections to permit weighing and to prevent the coal dust from escaping into the room when the weighing tanks were filled and emptied. The tests were started and closed with the feeder bins empty.

The feedwater was weighed in two water tanks placed on platform scales. The water supplied to the cooling coil was measured by a 2-in. water meter which was calibrated at the rate of feeding the water through the cooling coil, and its measurements were found reliable to within less than one-half of one per cent.

Flue gas samples were taken at six points in the uptake and collected over 1-hour periods. Flue gas temperatures were measured with thermocouples at the same six points where samples were drawn for analysis, and readings were taken every 15 min. The flue-gas temperature given Table LXLVII is the average of the measurements with the six couples.

Results of the Tests.—The results of the tests are given in Table LXLVII. The quantities of heat absorbed by the boiler, superheater and cooling coil, when the latter was used, are itemized separately. In the heat balance the losses by radiation are given by a separate item. In a series of tests on the same boiler and setting the radiation loss per square foot of exposed surface should be nearly constant and should vary only slightly by the capacity developed by the boiler. For the calculation of the radiation loss it was estimated that 250 B.t.u. were lost per square foot of the exposed surface per hour when the boiler was operated at 100 per cent of rating, and 350 B.t.u. when operated at 200 per cent of rating. The radiation loss was calculated according to the percentage of rating developed. These calculations of the radiation loss leave the true "unaccounted for," which consists largely of errors. In a series of well conducted boiler tests this true "unaccounted for" should be close to zero and should vary on both sides of the zero line according to whether the plus or minus errors predominate.

Effect of Fineness on Results of Tests.—It has been customary to state that in order to get good results the coal must be pulverized to a fineness of 95 per cent through a 100-mesh screen and 85 per cent through a 200-mesh screen. Table LXLVII gives the results of complete sizing tests of the coal burned in Tests 32 to 35, inclusive. The coal was much coarser than specified

TABLE LXLVII.—SUMMARY OF RESULTS OF 8 STEAMING TESTS ON AN EDGEMOOR BOILER BURNING POWDERED COAL AT ONEIDA STREET POWER STATION, MILWAUKEE, WIS.

Preparation of coal	Usual preparation			Coarser coal			Undried coal	
1. Test number	29	30	31	32	33	35	36	38
2. Duration, hours	23.72	18.17	23.62	23.60	22.47	23.53	23.43	16.73
Coal as Fired								
3. Per cent through 200 mesh				67.00	70.10	64.00		
3a. Per cent through 100 mesh	95.80		95.40	93.20	93.10	88.60		95.40
3b. Per cent through 40 mesh				99.20	99.20	98.00		
3c. Per cent through 20 mesh				99.90	99.90	99.80		
4. Moisture content, per cent	2.92	2.75	2.55	3.79	3.07	3.47	7.69	8.23
5. Volatile matter, per cent	36.66	37.45	36.58	36.57	36.29	36.27	35.82	34.70
6. Fixed carbon, per cent	46.63	46.08	48.07	48.43	49.01	48.87	45.74	44.67
7. Ash, per cent	13.79	13.72	12.80	11.21	11.63	11.39	10.75	12.40
8. Sulphur, per cent	3.64	3.49	2.92	2.40	2.66	2.99	2.10	2.90
9. Calorific value B.t.u	11,860	11,875	12,085	12,172	12,178	12,188	11,565	11,245
11 Coal fired per hour, lb	1,681	2,903	1,973	1,862	2,024	1,753	1,866	2,171
12. Coal fired per hour, per cu. ft. of combustion space	1.05	1.81	1.23	1.16	1.26	1.09	1.16	1.36
Ash and Refuse								
13. Carbonaceous content in furnace slag, per cent	0	0	0	0	0	0	0	0
14. Carbonaceous content in 2d and 3d pass refuse, per cent	3.49	5.00	5.25	9.52	7.19	7.37	4.97	4.49
15. Carbonaceous content in uptake dust, per cent	5.24	7.35	5.13	7.70	6.45	5.57	3.91	3.28
16. Calculated total carbon in refuse, per cent of coal fired	0.54	0.62	0.36	0.87	0.61	0.30	0.24	0.26
17. Softening temperature of coal ash, deg. F	2,050	2,210	2,120	2,120	2,110			
17a. Softening temperature of coal ash, deg. C	1,127	1,100	1,105	1,105	1,100			
Ash Account (per cent of ash fired)								
18. From bottom of furnace	25.50	41.50	48.10	10.10	24.10	59.40	48.10	41.60
19. From 2d and 3d pass	11.60	5.80	10.40	10.30	7.00	10.50	8.30	8.70
20. From dust collector	25.00	33.20	29.20	27.50	29.00	30.10	32.80	26.30
21. Unaccounted for	37.90	19.50	12.30	52.10	39.90	0.00	10.80	23.40
Air								
22. Temperature of air at furnace, 64 to 90°F. (18 to 32°C.)								
24. Excess air in flue gas per cent	22	18	18	19	15	25	19	20
Flue Gas								
25. Carbon dioxide, per cent by volume	14.90	15.40	15.50	15.30	15.80	14.60	15.50	15.40
26. Oxygen, per cent by volume	3.80	2.90	3.30	3.20	2.40	4.10	3.20	3.60
27. Carbon monoxide, per cent by volume	0	0.26	0	0	0.10	0	0	0
28. Pounds of dry flue gas per lb. of coal	11.20	10.60	11.00	11.30	10.80	11.70	10.70	10.60
29. Temperature of gases in uptake, deg. F	492	610	483	457	472	486	484	514
29a. Uptake, deg. C	255	321	250	236	244	252	251	268
Draft								
30. At uptake, inches of water	0.10	0.27	0.09	0.06	0.08	0.09	0.10	0.15

31. Top of furnace, inches of water	0.02	0.00	0.00	0.01	0.00	0.02	0.02	0.03
Steam and Water								
32. Steam pressure, lb. absolute	186	196	189	188	187	186	183	185
33. Superheat 53 to 102°F. (29 to 57°C.)								
34. Temperature of feed water, 98 to 108°F. (37 to 42°C.)								
35. Temperature of water to coil, 46 to 54°F. (8 to 12°C.)								
36. Temperature of water from coil, 118 to 151°F. (47 to 66°C.)								
Rates of Heat Absorption								
37. Per cent of builder's rating (boiler only)	103.9	167.4	111.7	102.7	112.4	104.8	101.9	113.5
41. Total hp. developed	502	812	589	549	601	528	527	586
B.t.u. Absorbed per Sq. Ft. of Heating Surface Per Hour								
42. By water in boiler	3,482	5,575	3,743	3,437	3,758	3,508	3,413	3,798
43. By steam in superheater	861	1,856	920	772	845	1,155	1,039	1,573
44. By water in furnace coil	No coil	No coil	33,900	37,600	40,770	33,190	21,920	18,440
HEAT BALANCE (Per cent. of heat in coal fired)								
Heat Absorbed								
49. By water in boiler	81.6	75.6	73.4	70.8	71.5	76.8	74.0	72.7
50. By steam in superheater	2.5	3.2	2.3	2.0	2.0	3.2	2.8	3.8
51. By water in coil	No coil	No coil	7.0	8.2	8.1	2.7	5.0	3.7
52. Total and thermal efficiency	84.1	78.8	82.7	81.0	81.6	82.7	81.8	80.2
Heat Carried Away								
53. By dry gases	9.1	11.4	8.9	8.2	8.6	9.5	9.0	9.9
54. By steam from burning hydrogen	4.3	4.2	4.1	4.1	4.2	4.0	4.2	4.2
55. By steam from moisture in coal	0.3	0.3	0.2	0.3	0.3	0.3	0.8	0.9
56. By steam entering with air	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1
57. Carbon monoxide	0.0	1.0	0.1	0.1	0.2	0.0	0.0	0.0
58. By carbon in ash and flue dust	0.6	0.7	0.4	1.0	0.7	0.4	0.3	0.3
59. By radiation	2.6	1.9	2.2	2.3	2.1	2.4	2.4	2.2
60. Heat unaccounted for	−1.3	1.6	1.3	2.9	2.2	0.6	1.4	2.2
61. Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

NOTE.—In the above table, the author has selected 8 representative tests out of the 11 tests made. Tests 28, 34 and 37 practically duplicated the results of tests given in their respective groups. It is of particular interest to note that in the tests made with undried coal, the carbon was a little more completely burned out of the ash than in the tests where dry coal was used. If sufficient moisture can be removed from the surface of the raw coal to allow of efficient pulverizing and subsequent handling, it would seem that mechanical dryers could often be replaced by a pneumatic handling system for conveying the raw coal from storage piles to the milling plant. This may remove sufficient surface moisture from coals of the higher ranks by atomization.

by the foregoing statement. The results of these tests seem to indicate that it is not necessary to pulverize the coal to the extreme fineness of 85 per cent through a 200-mesh screen in order to get good combustion and good efficiency. The completeness of combustion seems to be more a matter of a proper furnace and burner design and the right way of supplying air, than of the fineness of the coal. The losses due to coarseness of coal would be shown by the greater percentage of carbon in the refuse. The average loss due to this cause for the four tests with the coarser coal is 0.7 per cent. The average of this loss or the previous four tests is 0.6 per cent. The averages of the efficiencies are very nearly the same.

The ability to burn coarser coal means increased capacity of the pulverizing mills and decreased cost of coal preparation.

Effect of Moisture in Coal on Results of Tests.—Another statement that has been generally accepted is that coal must be dried to about 1 per cent moisture in order to be successfully burned in pulverized form. In order to determine to what extent this statement is true, Tests 36, 37 and 38 were run with undried coal. The results of the tests show that the completeness of combustion was as good as with the dried coal. There was no loss due to CO in the flue gases and the losses due to combustible in the refuse averaged only 0.3 per cent for the three tests, which is in fact less than the average with the dried coal.

The losses due to moisture in coal of course increased 0.5 to 0.6 per cent, which increase is at the rate of about 0.1 per cent for every 1 per cent of increase of moisture in the coal. The average decrease in the boiler efficiency for the three tests is about 0.7 per cent, which checks closely with the increase in the losses due to increased moisture in the coal. It seems, therefore, that it is not necessary to dry the coal down to 1 per cent of moisture in order to get good boiler efficiency. In fact, it seems that most of the eastern coals can be pulverized and burned with good results without drying.

Capacity of Boiler that can be Developed with Pulverized Coal.—The boiler capacity that can be developed with pulverized coal depends entirely upon the size and shape of the furnace. With the present knowledge of the art of burning powdered coal the best results are obtained when the coal is burned at the rate of 1 to 1½ lb. per cubic foot of combustion space per hour. Good results can be obtained when the coal is burned at rates

varying from ½ to 2 lb. per cubic foot of combustion space per hour, which gives a considerable working range. In Table LXLVII, the rate of combustion is given by item 12. The range covered by this series of tests is from 1.05 to 1.81 lb. of coal per cubic foot of combustion space. If it is desired to operate the boiler at high rates of working, a large furnace must be installed and the combustion space must be so arranged that the flames are given the longest possible path through the furnace. The design of burners and the admission of air are very important at high rates of combustion. It appears probable that future developments in the design of furnaces, burners and the air supply may make possible higher rates of combustion than the limit given above.

The function of the "furnace coil" is to chill the descending particles of partially fused ash by radiation in order to prevent the formation of slag and, thereby, facilitate their removal from the furnace. In the Lakeside plant this is known as the "water screen."

Experience with Oneida Street Station.—This installation has now been in regular operation on pulverized coal for a sufficient time to demonstrate what can be expected in the way of reliability. "It is a combined heating and power plant, the principal load being the heating load, and has been in operation for nearly three years. No operating difficulties of any kind have been encountered. There have been no interruptions to service due to its powdered coal operation, and the plant has met every requirement, including the very severe winter of 1919–1920. The importance of the plant is indicated by the fact that it heats practically all of downtown Milwaukee."

The Lakeside Station at Milwaukee.—The primary object of making a thorough trial of pulverized coal at the Oneida Street station was to determine the suitability of this fuel for use in a new station which was being planned by the Milwaukee Electric Railway & Light Co. The new station has now been in operation for about a year, and is the first large central station designed for the exclusive use of pulverized coal. Great credit is due John Anderson, chief engineer of the company, for his pioneer work in this field and his courage in making such a radical departure in power-station design. The tests on No. 8 boiler at the Lakeside plant, made by Henry Kreisinger, have clearly demonstrated that it is possible to obtain efficiencies, with

pulverized coal, which are fully equal to those obtained in the best oil burning plants, and 2 or 3 per cent better than has been done with the best stoker installations.*

This station is designed for future extension on the sectional principle, each succeeding section being a self-contained unit. The equipment of the first section includes the following major items:

8—1,306 hp. Edgemoor boilers with economizers.

2—20,000 kw. General Electric 60 cycle turbo-generators.

Coal unloading, drying, and pulverizing equipment, having a capacity equal to twice that of the maximum daily demand of the present furnaces.

Switching equipment for generators and distributing feeders.

The pulverized coal equipment includes Fuller-Lehigh mills and the Fuller-Kinyon pulverized coal conveying system. The boilers are equipped with the Lopulco system. The principle dimensions of the boiler and economizer are as follows:

Boiler—Edgemoor four-pass with 563 4-in. tubes 20 ft. long (15 tubes high by 37 and 38 wide), and 5 steam drums. Total heating surface, 13,060 sq. ft.

Water Screen—22 4-in. tubes, each with an average exposed length of 13¾ ft.; total heating surface of exposed part of tubes, 320 sq. ft. Total heating surface of boiler and water screen, 13,380 sq. ft. The water screen corresponds to the "furnace coil" used in the preceding tests.

Superheater—Foster.

Economizer—Sturtevant, with 528 4½-in. O. D. cast-iron tubes 12 ft. long (12 wide by 44 long); provided with a steam-turbine-driven induced-draft fan.

Furnace—Average width, 22 ft.; average length, 14 ft.; height under tubes, 25 ft.; height under arch, 22 ft.

Burners—6 flat Lopulco burners used; air supplied to feeders and burners under pressure of 12 in. water.

These tests were run by the U. S. Bureau of Mines for the Combustion Engineering Corp. and were all personally supervised by Henry Kreisinger. The high efficiency is possible because with powdered coal the proper ratio of air to coal can be easily maintained so that there is very small loss due to excess air and practically no loss from incomplete combustion and combustible in refuse. The experience of this company with stokers indicates that these losses range from 6 to 10 per cent higher. It is doubtful if a long series of stoker tests have ever been made that would in any way compare with the tests made by Mr. Kreisinger and reported here in summary form.

* Editorial by E. B. Ricketts, *Mech. Eng.*, Oct., **1921**, 692.

POSSIBILITIES OF PULVERIZED FUEL FOR CENTRAL STATIONS

The foregoing reports appear to indicate that, insofar as test efficiencies are concerned, pulverized coal and modern stokers are almost on a par when burning high-grade coal. Apparently, there is a sufficient margin, in the case of pulverized fuel, to offset the cost of preparation. The items of power required for preparation, and thermal losses in the dryer, may represent 2 or 3 per cent of the calorific value of the coal. A detailed comparison of pulverized coal and stokers will be found in the *Report of the Prime Movers Committee*, N. E. L. A., **1912**, pages 228 and 229.*

The Combustion Engineering Co. states: "We have not considered the coal used for the dryer, as it has been demonstrated that dryers are certainly unnecessary for coals containing less than 6 per cent of moisture and probably more; and for coals containing more moisture than this, theoretically the amount of heat required by the dryer would not be materially different from that required to eliminate the excess moisture in a stoker furnace."

Welles and Jacobi† state that "the conclusion to be derived is that, other things being equal, the competition between the use of pulverized coal firing and stokers for large boiler plants will be a matter of flexibility of service, convenience in operating, and maintenance cost."

Relative Power Requirements.—With further reference to the statement that these were approximately equal, in the case of pulverized coal and stokers, it is of interest to compare the requirements for auxiliary power.

The following table gives actual operating data for a 600 hp. Babcock & Wilcox boiler equipped with an underfeed stoker, of a modern type, and with inclined baffles.

Average steam pressure, lbs. per sq. in. No superheat	200
Average output, lbs. steam per hr., steam flow	32,807
Per cent of nominal rating	183
Temperature of flue gases, degrees	465°F.
	240°C.
Temperature of feed water, degrees	198°F.
	92°C.

* The same volume contains, on pp. 237 to 245, an extensive bibliography of pulverized coal from *Industrial Arts Index*, 1913 to 1920.

† *Mech. Eng.*, Sept., **1919**, 746.

Calorific value of coal, B.t.u. per lb	14,040
Efficiency of boiler & furnace, per cent	76
Coal consumed, lbs. per hr	3,080
Air pressure in blower box, inches water	5.0
Air pressure in tuyeres, inches water	3.2
Average CO_2 in flue gases, per cent	14.9
Maximum theoretical CO_2, per cent	19.4
Excess air, per cent	30.0

$$\frac{19.4 - 14.9}{14.9} = 0.30$$

Steam used by blower engines, lbs. per hr	1.650
Steam used by stoker engines, lbs. per hr	290
Steam used by stoker & blower, lbs. per hr	1,940
Per cent of total steam generated	5.9
Per cent of available heat in steam, above temp. of steam in the condensers of the main turbines	3.0

(Exhaust steam from auxiliaries used for heating feed water.)

In oil-burning boilers the proportion of steam required for atomizing the oil ranges from 2 to 3 per cent. With mechanical atomizers much less power is required by the oil pump.

The power required for operating the dryer and pulverizer and for distributing and firing pulverized coal with stack draught, according to Savage,* is about 20 kw.-hrs. per ton. The above boiler burned 3,080 lbs., or 1.54 tons, of coal per hr. which would require 30.8 kw. per boiler. In a plant having a sufficient number of boilers to require a house turbine of 750 kw. rating, the auxiliary power can be generated with a steam consumption of 33 lbs. per kilowatt-hour, using saturated steam at 200 lbs. per square inch and exhausting into a feed-water heater at atmospheric pressure. The steam required is then 1,020 lbs. per hour, or 3.1 per cent of the steam generated. This would correspond to about 1.5 per cent of the available heat supplied by the boiler. When using steam with 200°F. (110°C.), superheat, the turbine consumption will be reduced from 33 to approximately 29 lbs. per kw.-hr., a reduction of about 12 per cent.

In the case of the blower and stoker engines the corresponding gain in steam economy will be only about 1 per cent. when using superheated steam. On the other hand, the more usual practice in new stations is to drive the blowers and stokers electrically, and this will effect a considerable reduction in the amount of steam required, possibly reducing it by about 40 per cent. The

*"The Use of Powdered Coal under Steam Boilers," by H. D. Savage, presented before the *Am. Iron & Steel Inst.*, May 27, 1921.

proportion of the available heat *required would then* be about 1.8 per cent.

When using types of burners for pulverized coal which require forced draught, the power requirements will be greater. Allowing for the same duct losses as in the above table, the power required by the fans should not exceed 50 per cent of the power required for the stoker fans, and this might be reduced by the use of larger or shorter air ducts.

The power requirements of one representive system of preparing, conveying, and burning pulverized coal are about 35 hp.-hr. per ton. With a motor efficiency of 89 per cent, this corresponds to a power consumption of 29.4 kw.-hr. per ton.

Some systems will require less power and others more, according to the methods used in pulverizing and conveying. Some types of air transport systems require more power for their operation than mechanical systems, but have the advantage of greater simplicity and flexibility. This will be partially offset by the power required for conveying the stoker coal. The proportion of the available energy in the steam, which will then be required for auxiliary power, may be about 1.8 per cent.

Range of Fuels.—An important advantage of pulverized fuel firing is its adaptability to a wider range of fuels than can be burned on stokers, notably the following:

1. Coals with a high content of ash, moisture or sulphur.
2. Finely divided fuels, like slack, culm, and coals which have been subjected to cleaning processes.
3. Highly coking coal which cannot be readily burned on stokers.
4. Semi-coke from low-temperature distillation processes.

The same furnace is available for burning all grades of coal in pulverized form. Different types of stokers, on the other hand, are often required for burning different kinds of raw fuel. Low volatile fuels are being burned in pulverized form, including anthracite with a volatile content as low as 6 per cent, which has been dredged from the beds of rivers. A preliminary test with pulverized semi-coke, of 9 or 10 per cent volatile content, indicates that it may be burned with as good results as bituminous coal.

Intermittent Loads.—Another important advantage is the facility and economy with which fires may be banked, and the ease with which they may be restarted when steam is wanted

suddenly. As mentioned in Chap. V, this makes pulverized fuel especially desirable in the following cases:

1. In steam reserve stations connected to waterpower or other transmission systems.

2. For carrying peak loads in power systems where the base load is carried by units which it is desirable to operate continuously, as in the following cases:

(*a*) High efficiency prime-movers already served by stoker-fired boilers.

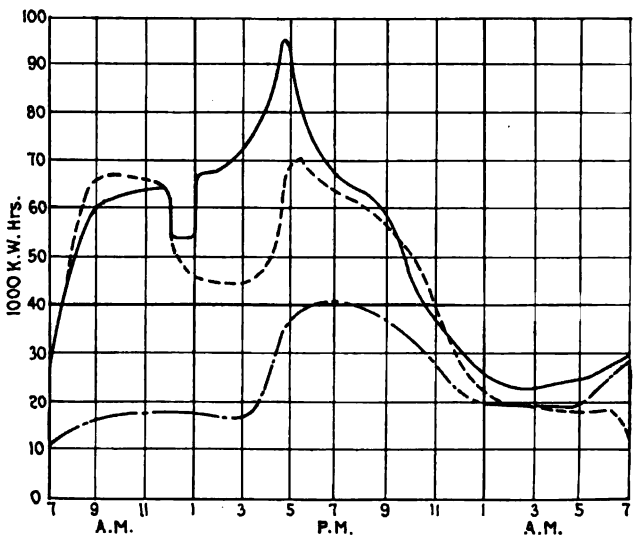


FIG. 162.—Representative daily load curves for the four months of November, December, January, and February.

(*b*) Boilers fired with blast-furnace gas or by-product producer gas.

In the latter case gas and pulverized fuel may be burned either in the same boiler (see page 704) or in separate boilers (see page 386).

Figures 162 and 163 show a typical set of load curves for a central station in a large city.* The winter peak, due to the lighting load, runs up to 95,000 kw. and the various curves are selected for representative days under summer and winter conditions. The approximate annual load factor, figured from these curves, is 40 per cent. A horizontal line has been drawn

* Reproduced by courtesy of the Edison Electric Illuminating Co., of Boston, Mass.

at a load of 40,000 kw. to divide the load into what may be considered as base and peak loads, and the following table gives the load factor of each part.

TABLE LXLVIII.—STATISTICS CORRESPONDING TO LOAD CURVES IN FIGS. 162 AND 163

PART OF LOAD	TOTAL	BASE	PEAK
Maximum kilowatts	95,000	40,000	55,000
Annual output in kilowatt hours as per curves	331,000,000	268,000,000	61,800,000
At 100 per cent load factor	830,000,000	350,000,000	480,000,000
Load factor, per cent	39.8	76.5	12.9
Percentage of total annual load	100.0	81.0	19.0

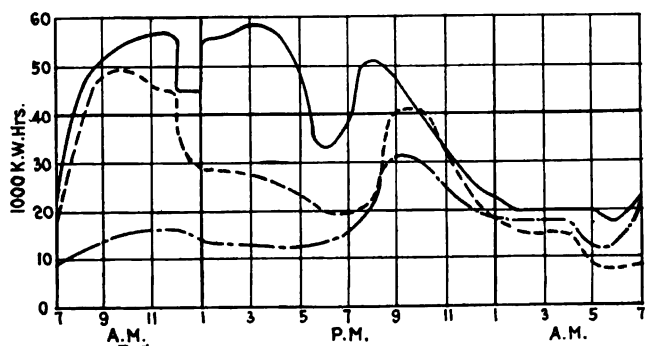


FIG. 163.—Representative daily load curves for the eight months from March to October, inclusive.

The load factor of 76.5 per cent, for the base load, is sufficiently high for carrying with a by-product producer, since a large part of the idle periods for the producers would occur on Saturdays and Sundays. The base load represents such a large proportion of the total annual output that the recovery of nitrogen products from the coal should offer a sufficient economic incentive for carrying this part of the load with by-product producer gas, and for increasing the base load output by the further use of electric vehicles for local commercial service. The increasing cost of gasoline should make it easier to increase this battery-charging load and thereby fill up the night valley in the load curve (see end of Chap. V).

In Table LXLIX it is assumed that the night valley in the base load curve, in Figs. 162 and 163, is filled up to the 40,000 kw. line on six nights per week.

The area of the night valley is a little smaller in winter than in summer, but this may also be true of the battery charging load, owing to weather and traffic conditions. The additional load is, therefore, figured on the basis of the areas of the week day night valleys for the summer and winter curves, respectively, and amounts to a total annual load of about 44,000,000 kw.-hr. for 305 business days.

TABLE LXLIX.—STATISTICS CORRESPONDING TO LOAD CURVES WITH ADDITIONAL BATTERY CHARGING LOAD

PART OF LOAD	TOTAL	BASE
Maximum kilowatts	95,000	40,000
Annual output in kw.-hr.	375,000,000	312,000,000
Load factor, per cent	45.2	89.0
Percentage of total annual load	100.0	83.3

The average annual power consumption for electric trucks is about as follows:

½-ton truck	4,120 kw.-hr.
1-ton truck	5,240 kw.-hr.
2-ton truck	6,400 kw.-hr.

Assuming an average efficiency of 85 per cent for the transmission distribution and conversion of electric current for charging the batteries, in the city and suburban districts, a 1-ton truck will require approximately 6,200 kw.-hr. at the power station bus. On this basis, an annual battery charging load of 44 million kw.-hr. will supply about 7,100 trucks. In 1917, taking a specific example, about 23,000 horses were in use in the city of Boston. If each electric truck replaces 5 horses, about 4,600 trucks will be required without displacing any gasoline trucks. The suburban districts supplied by the same power system should be able to employ the balance of the electric trucks. The system to which these load curves apply includes only a small proportion of street railway loads in suburban territory. When the system load is more diversified, the load factors are higher and a similar proportionate division into base and peak loads may be effected with less dependence upon the electric vehicle load.

On a system with these load characteristics the component of the maximum peak load above the 40,000 kw. line, is greater than the rather high limit set here for the base load, and the advantage of carrying this with pulverized fuel is increased by the low load

factor and by the consequent opportunity for the elimination of banking losses. Moreover, only a small percentage of the total fuel supply need be pulverized.

Owing to the limited trials thus far made with granulated fuel (page 665), it is impossible to form an opinion as to its possible merits for carrying base loads, where pulverized fuel is used for carrying the peak load; but it is worthy of further investigation and might be applicable in some cases.

Effect of Variable Load on Station Economy.—A large central station, having a load factor of about 37 per cent and equipped mainly with overfeed stokers, showed an average consumption of 1.953 lb. of coal per kilowatt-hour for the year 1916. The over-



FIG. 164.—Fuller-Lehigh indirect fired dryer.

feed stokers could be economically banked, the consumption being only 35 lbs. of coal per hour for each 500-hp. boiler, but 1,500 lb. were required to bring the fire back into condition for operation. When a fire was allowed to go out, 1,000 lb. of coal were left on the grate and credited to the plant, while 6,000 lb. were required to light a boiler and bring it to steaming condition, ready to put on the line. Forcing a boiler for one hour required 600 lb. of coal.

Allowing for these losses, it was estimated that the station economy, with constant load, would be 1.71 lb. of coal per kilowatt-hour, which corresponds to a reduction of 12.5 per cent in the coal consumption. It was also estimated that additional load could be taken on to the existing plant, if it were evenly distributed over the 24 hr., at an economy of 1.56 lb. of coal per kilowatt-hour—a reduction of 20 per cent. The coal consumed in banking fires and bringing them back into steaming condition was about 3.76 per cent of the annual consumption.

Another large system has 15 stations feeding into it, 85 per cent of the total annual load being carried by four stations, and 37.1 per cent by the most modern station. This station is equipped with underfeed stokers and operates at a load

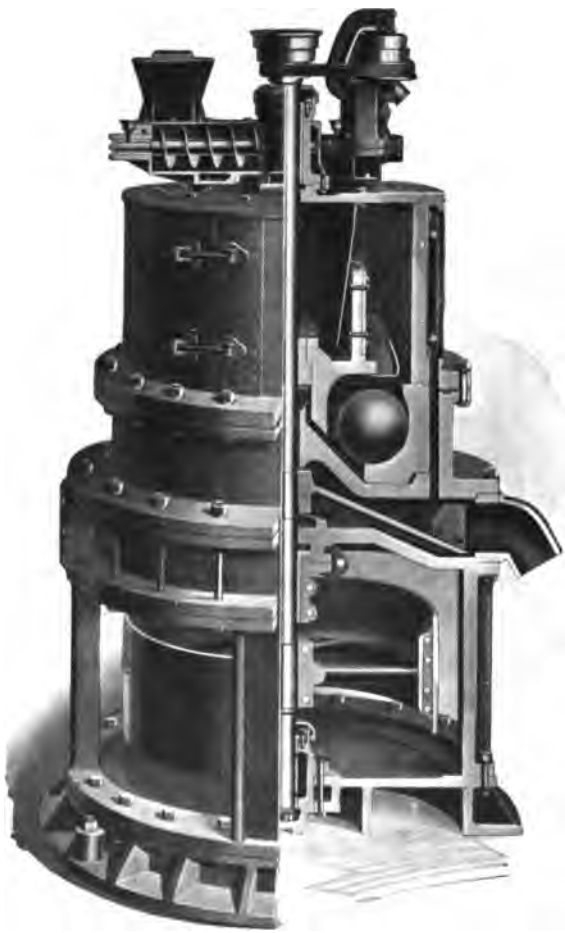


Fig. 165.—Fuller mill.

factor of 43.25 per cent, based on the maximum peak for the year, and 0.81 per cent of the annual coal consumption is due to banking fires. The losses due to burning out and relighting fires, for cleaning and repairing boilers, bring these losses to approximately 1.5 per cent.

The banking losses for the entire system are as follows:

Average annual banking losses	3.06 per cent
Maximum month (August)	3.60 per cent
Minimum month (December)	2.68 per cent
System load factor, based on maximum peak for the year	43.73 per cent
Fuel consumed for banking at any one station during any one month in the year:	
Minimum	0.33 per cent
Maximum	22.68 per cent

In the stations operated by a third large company the coal used for maintaining banked fires runs from 5.5 to 6.5 per cent of the total coal used. This is for a load factor of approximately 34 per cent. Underfeed stokers are used in the larger plants.



FIG. 166.—Rotating element of Fuller mill with balls, pushers, plows and fan blades.

The above systems are located in the vicinity of Boston and New York, and the fuel used is largely semibituminous coal from Virginia and West Virginia.

Where coal is burned on stokers in stations which are used for standby service, during several months out of the year, the consumption of coal in banked fires is a considerable item of expense. This applies, particularly, in the case of steam reserve stations for hydro-electric transmission systems where steam must be kept up to maintain service in case of a failure of the

transmission line. It would also apply where the base load is carried in one type of power station and the peak loads in another type of station. This will be the case when the base load is carried with by-product producer gas and high efficiency turbines,

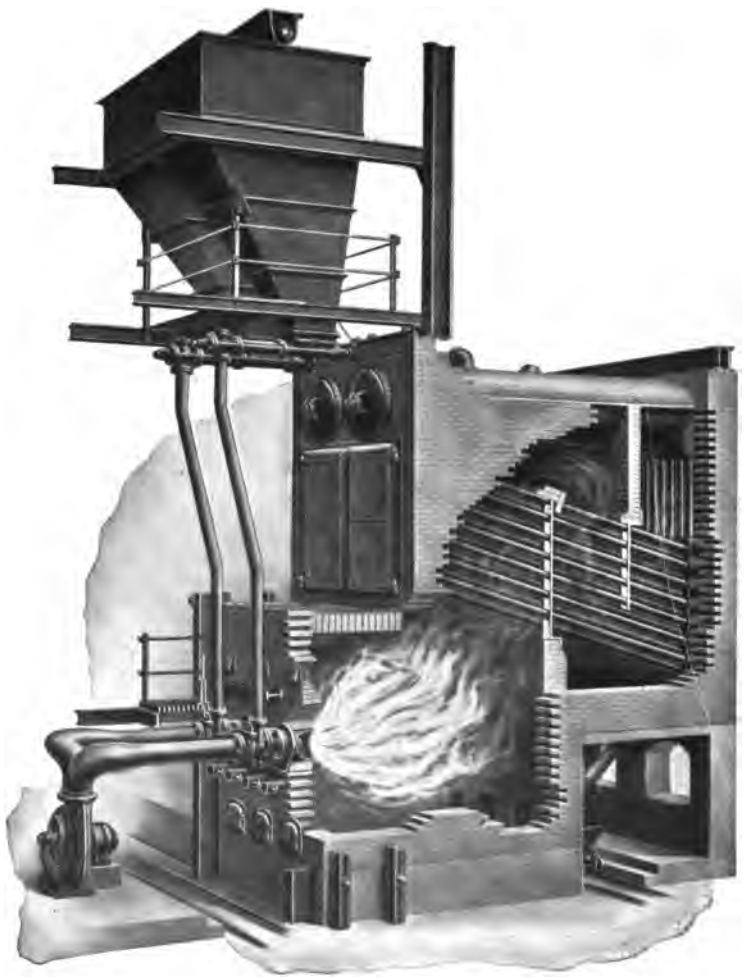


FIG. 167.—Babcock and Wilcox horizontal type boiler equipped for firing with pulverized coal, Fuller Lehigh system.

operating with high-pressure steam or with a binary vapor cycle, while the peak loads are carried in separate stations with solid fuel and ordinary steam pressures. Industrial power plants

present a third case, especially where most of the load lasts during a single working shift.

The amount of coal burned during banking periods varies with the service conditions. Many of the central stations which supply large cities have to provide light for a large number of office buildings when a thunderstorm suddenly approaches and dark clouds interrupt the daylight. This necessitates carrying banked fires in the summer season to nearly the same extent as in the winter. In fact, the highest peak load of the year is sometimes caused by summer thunderstorms.

Banked fires are carried at "hot bank" or "cold bank," according to the time available for getting a boiler on the line and under full load. A "hot bank," or "live bank," consists in carrying full steam pressure and having the fire in condition to get the boiler up to normal rating in from 5 to 7 min. A "cold bank," or "dead bank," consists in burning only enough fuel to keep up a low steam pressure. On modern underfeed stokers the average coal consumption during banking is about as indicated below. The "time" is that required to bring the boiler up to normal rating (*i.e.*, "nominal or 100 per cent" rating).

Fire	Time, minutes	Coal consumption		
		Pounds per hour*		Percentage of fuel at full load
		Average	High figure	
Live bank	5 to 7	0.5	0.66	7.5 to 10.0
Dead bank		0.2	0.33	2.5 to 3.5
After 24 hr	11 to 15			
After 43 hr	25			

* Per rated boiler horsepower.

When a fire is run on "dead bank" for a considerable period, the accumulation of ash renders it impracticable to start up as rapidly as after a shorter period. The percentage consumed during banking is based on the fuel consumed when the boiler is operated at about 175 per cent of its normal rating, this being considered as full load. In carrying peak loads the boiler may be forced to 250 or 300 per cent of its rating. An average figure for live and dead banking may be taken as 5 per cent of the full load consumption.

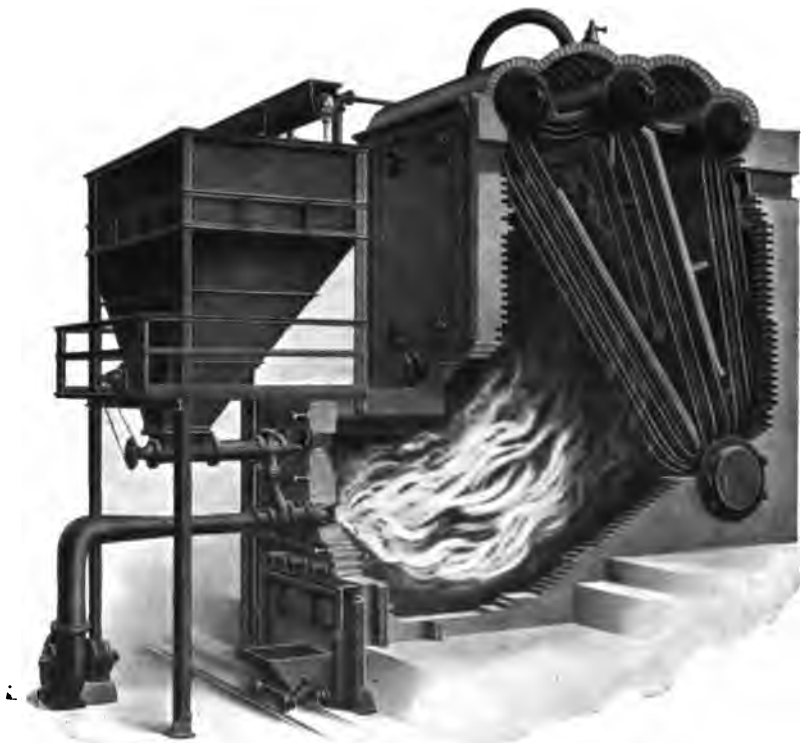


FIG. 168.—Stirling boiler equipped for firing with pulverized coal, Fuller-Lehigh system.

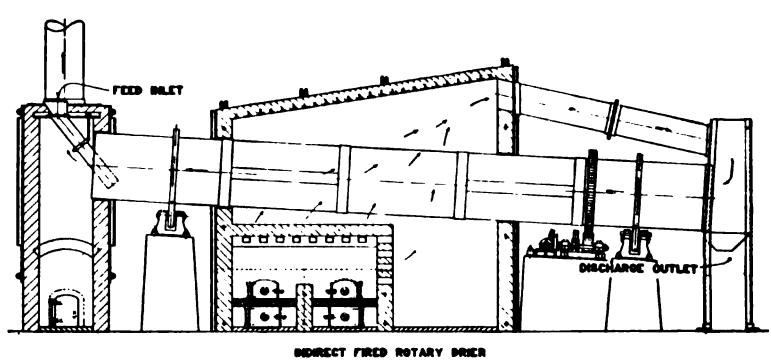


FIG. 169.—Diagrammatic view of Fuller-Lehigh dryer.

In Figs. 162 and 163, the peak loads above the assumed base line of 40,000 kw. have a load factor of about 13 per cent, leaving a gross idleness factor of 87 per cent. If the boilers are forced to 250 per cent of rating while carrying the peaks, the net idleness factor may be taken as 60 per cent. It will not be necessary,

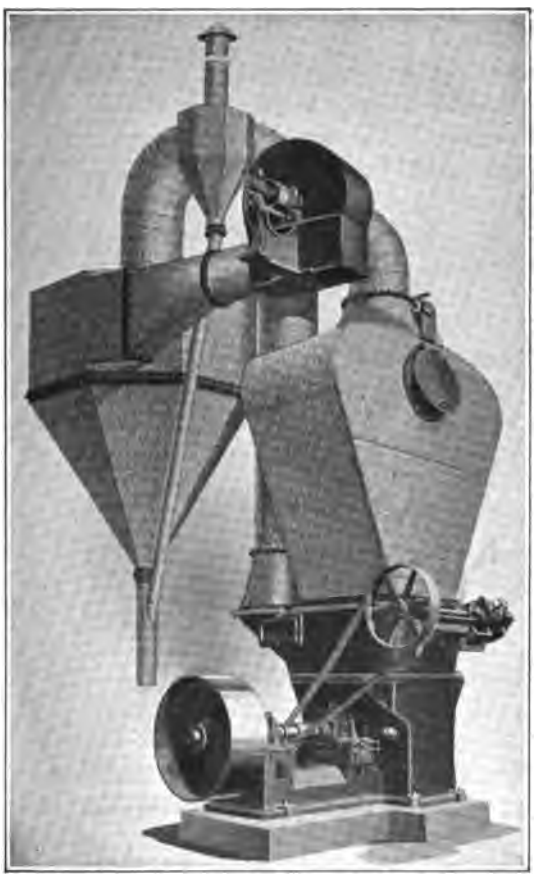


FIG. 170.—Bonnot mill with cyclone separator.

however, to keep all boilers banked during this part of the time, so we shall assume that this factor may be reduced to 33 per cent. Then the ratio of the fuel consumed in banked fires to that used while carrying load will be $\frac{0.05 \times 0.33}{0.13} = 0.127$, or approximately as 1 to 8. Possibly this ratio will range from 10 to 15 or 20 per cent, according to the conditions.

Where pulverized fuel is used, steam has been held over night with only a small drop in pressure and, in the morning, about 4 min. firing sufficed to bring the pressure up to normal. This indicates that it will only be necessary to burn fuel at intervals of several hours, to maintain steam pressure in continuous standby service comparable with live banking on stokers. The equivalent of dead banking conditions may be provided by less frequent firing, or a further economy may be effected if fuel is burned only under a single boiler in a battery. Steam pressure can be maintained in the remaining boilers by circulating either steam or hot water through them from the live boiler. This will eliminate furnace losses in all of the boilers but one. A cold boiler may be brought up to full pressure in ½ hr. with pulverized coal, but it is hard on the boiler, owing to the rapid expansion of the metal. It is better practice to allow an hour and a half for heating up; hence the necessity for keeping the boilers hot where service is required in emergencies.

It will then only be necessary to heat the brickwork. When banking with pulverized coal, the consumption should be considerably less than with stokers, as the draft may be shut off.

Anthracite is under a disadvantage, as compared with bituminous coal, in heating up a cold boiler and furnace, owing to its its slower ignition at low temperatures. This is equally true whether it is burned on stokers or in pulverized form. Where frequent or rapid starting is required, it may be advisable to provide an auxiliary supply of bituminous coal for this purpose, especially in the case of stokers of the travelling-grate type, which are suitable for burning either anthracite or bituminous coal. In the Mt. Vernon St. station, of the Philadelphia Rapid Transit Co., pulverized anthracite is being used in intermittent service for carrying peak loads. Auxiliary oil burners are installed and are used for warming the furnace before turning on the pulverized fuel. With semi-coke, on the other hand, it may be practicable to leave sufficient volatile matter in the fuel, and to make it of such a structure that it will ignite more readily than anthracite.

Low volatile fuels, like semi-coke and anthracite, are convenient to keep in storage for long periods at a steam reserve station, owing to their freedom from susceptibility to a spontaneous ignition.

Combustion Control.—When operating with constantly varying loads it is often difficult to control the combustion conditions to correspond with each change in load as promptly as is desirable. Pulverized coal is more responsive to delicate control than solid fuel fires and this introduces another factor in its favor, which should render it possible to attain better efficiency.

Devices for combustion control, both of indicating and of automatic types, are coming into more frequent use. These should improve the conditions when burning either solid or pulverized fuel.

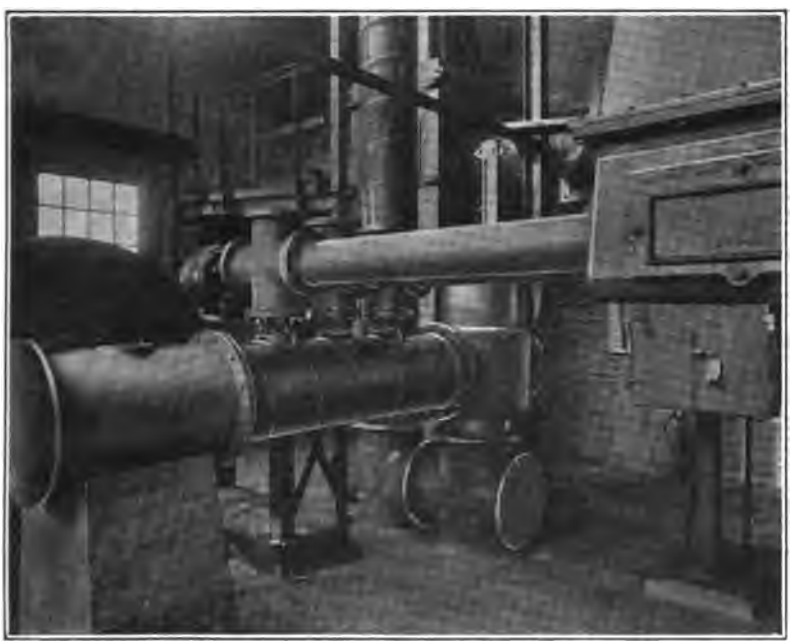


FIG. 171.—Bonnot coal-feeding mechanism. View showing the feed screw connected with the feeder box on the suction side of the distributing blower.

Investment Required.—When operating with a good station load factor, the investment required for a pulverized coal installation is comparable with that required for a stoker installation. As the load factor becomes poorer, however, the pulverized coal installation will cost less in proportion, provided the fuel requirements are sufficient to enable the preparation plant to operate at a good load factor. Sufficient storage capacity is installed in all stations for carrying the daily peak loads. Thus the fixed

charges can be reduced on the pulverizing plant, while it is necessary to install stokers under all the boilers where they operate with a poor load factor.

When using stokers and carrying steady loads, the boiler is generally operated at an economical rating; *i.e.*, between 100 and 175 per cent. When steam is drawn from the same boiler for carrying peak loads, it is forced to 250 or 300 per cent of rating for limited periods. Under these conditions the efficiency of both the boiler and furnace fall off considerably. The loss in furnace efficiency is due to incomplete combustion of the fuel owing to: (1) the loss of carbon monoxide with the flue gases, (2) the carrying of unburned coke cinders up the stack, (3) possibly an increased percentage of carbon rejected with the ash, and (4) possibly an increased percentage of excess air is required for limiting furnace temperatures.



FIG. 172.—Bonnot air indicator.

From the viewpoint of the investment in stokers, it is obviously more economical to build furnaces of a suitable size to accommodate stokers of moderate capacity, and to sacrifice efficiency when operating them at high rates of driving. With pulverized coal, on the other hand, the cost of the furnaces alone need be considered. It is more likely that the additional investment required for building the furnaces of sufficient size to ensure complete combustion, when carrying peak loads, should be offset by the saving in fuel which will result.

Base Loads.—These considerations do not apply in the case of stations or units operating largely on base loads. In this case the most modern practice is to install each turbine and its group of boilers as an independent unit, and to keep this unit operating day and night at its most economical loading. The most

favorable applications for pulverized fuel, in carrying base loads, should be in cases where low-grade fuels are locally available which can be obtained at a sufficiently low price to compete with grades which are more suitable for burning by other methods.

The results attained at Milwaukee, however, indicate that pulverizing is worthy of consideration, even where base loads are carried with high-grade coal; at least for new installations and for the replacement of obsolete equipment.

While the superior economy of pulverized coal in banking fires is a minor point in some instances, yet it is one of a number of advantages, which may be summarized as follows:

1. Low grade and by-product fuels may be burned in pulverized form to better advantage than on stokers.

2. No machinery is used in the furnaces, and the designers of boilers and furnaces are given a wider latitude for making improved designs, using preheated air, etc.

3. Complete and smokeless combustion may be attained with a minimum of excess air.

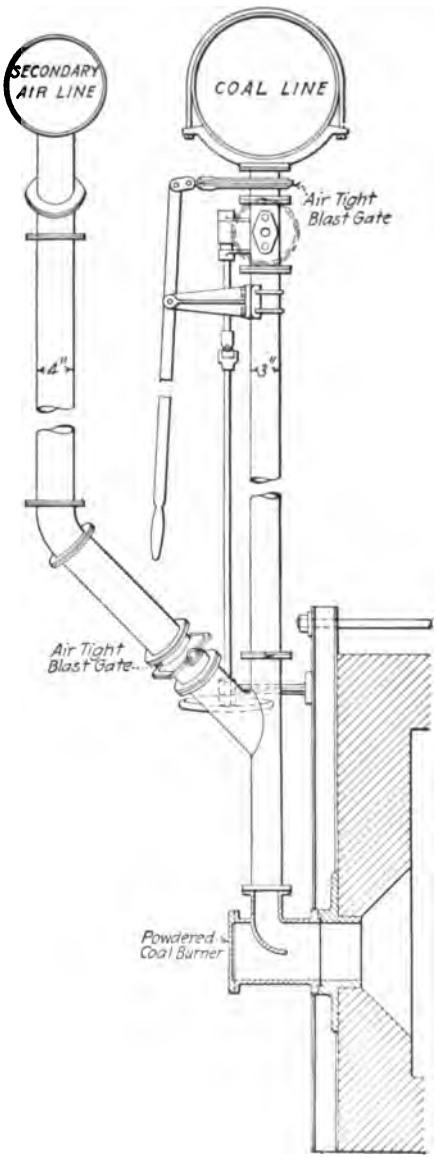


FIG. 173.—Bonnot burner for pulverized fuel.

4. Greater flexibility of furnace control is possible.
5. Standby losses are reduced to a minimum.

From the point of view of the engineers having to do with the design and development of steam turbines and electrical machinery, it is rather discouraging to see old and wasteful methods of burning fuel persist in the boiler room. They have been gradually bringing the equipment of the generating room up to the highest attainable efficiency by refinements in design and construction. It does not require much in the way of careless firing to nullify their efforts when the overall efficiency

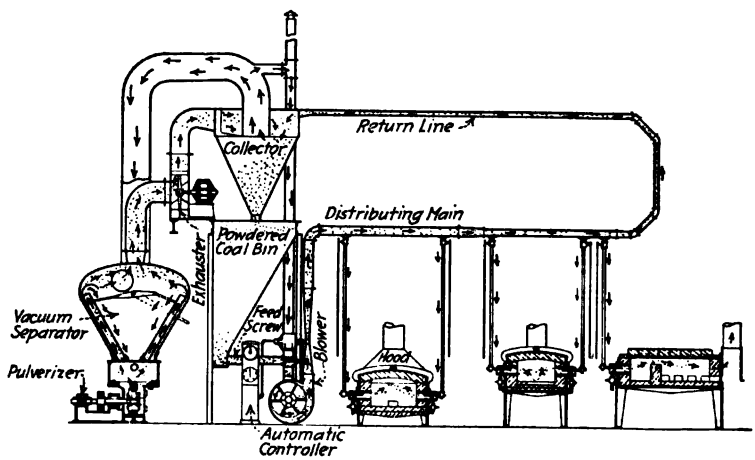


FIG. 174.—The Holbeck low-pressure distributing system.

of the central station is *the* important consideration in generating electricity from coal.

The underfeed mechanical stoker has much improved the efficiency of the boiler furnace, but it still has its limitations, especially when burning low-grade fuel. With the development of efficient methods of handling and burning pulverized fuel, the power station engineer has another method at his disposal for solving his problems. It may not be universally applicable, in the present state of the art, but it is a great advantage to have two good methods of burning coal under boilers to choose from, each of which has its advantage for certain applications.

The efficient utilization of our low-grade fuels is a matter of ever increasing importance. The re-equipment of old boiler

plants for burning pulverized coal may often be more easily accomplished than the installation of efficient stokers, even when good coal is burned.

The relative economic value of fuel economy in power stations is well illustrated in the case of a new turbine which excels an older one in steam economy by one per cent. If the new machine is operated continuously (on base load service), the cost of the fuel saved, when capitalized, will often pay for the new machine and make it possible to scrap the old one or to relegate it to peak load service (page 326).



FIG. 175.—Application of powdered coal with the secondary air to the burner, using the Holbeck system.

It is, therefore, evident that, if a saving of from 3 to 10 per cent, or more, in fuel economy can be made by the substitution of pulverized coal for old installations of stokers, the cost of the change will soon be offset by the saving in fuel. In the case of peak load stations, the saving of one-half the fuel required for banked fires will be just as important as a saving of similar magnitude in the fuel used for carrying the base load. In fact, the banked fires are, in reality, the base load of these stations.

Acknowledgements

The preparation of this contribution of "American Fuels" has been made possible by the cooperation of the companies and individuals already mentioned, as well as many others, and the authors wish to express their appreciation of their assistance. Valuable aid has also been rendered by members of the General Electric Company's organization. In addition to those already mentioned, the authors are indebted to the following, either directly or indirectly: W. R. Whitney, W. L. R. Emmet, B. P. Coulson, A. H. Kreusi, B. L. Spain, P. T. Hanscom, R. S. Scott, H. C. Fairbank, L. W. Cooper, A. W. Nisbet, S. A. Moss, E. Pragst, J. Liston, and others. The editorial and circulation staff of the *Gen. Elec. Rev.*, including J. R. Hewett, L. E. Saunders, B. M. Eoff and W. D. Brough, have been of especial assistance in connection with the preparation of the series of articles entitled "Methods for More Efficiently Utilizing our Fuel Resources," which were published in that magazine during 1917, 1918 and 1919. The author had their cordial assistance in the collection and editing of the series which prepared the way for, and rendered possible the preparation of, the four preceding chapters in "American Fuels."

Valuable assistance has also been rendered by the following: V. Starzenski, Adirondack Power and Light Corp.; R. H. Burdick, Electric Bond & Share Co.; R. E. Dillon, and others, Edison Electric Illuminating Co., of Boston; C. H. Baker and V. Frost, Public Service Electric Co. of New Jersey; W. S. Monroe, and others, Sargent & Lundy, Chicago; E. B. Powell, and others, Stone & Webster, Boston; G. I. Rhodes, of Ford, Bacon and Davis, New York; C. G. Gilbert, of Arthur D. Little & Co. (and while curator of Mineral Technology in the U. S. National Museum); O. P. Hood, U. S. Bureau of Mines; and H. Goodwin, Jr., of the staff of the Superpower Survey.

The authors are also under obligations to the following, with whom it was their pleasure to be associated in connection with fuel investigations undertaken during the war in cooperation with the Government: Hudson Maxim, U. S. Naval Consulting Board; and Lindon W. Bates, Submarine Defense Association. Also to the Quigley Furnace Specialties Co., the Fuller Engineering Co., and the members of their staffs already mentioned in Chap. VIII.

The authors wish to express their especial appreciation of the cordial coöperation of W. A. Hamor. They are also under obligations for courtesies extended by the managers and others during visits to various industrial plants.

CHAPTER IX

THE DEVELOPMENT OF MECHANICAL STOKERS

By A. W. Smeltz*

In firing a boiler the best results are obtained by the continuous or uniform rate of combustion of coal. To get these results, the firing must be done frequently in very small quantities or continuously. This condition is difficult to obtain with hand-firing, since firemen prefer to shovel in a large quantity of coal and then rest. If it is obtained with a hand-fired furnace another difficulty arises. When the furnace door is opened for firing, a large quantity of air is admitted over the fire, and this lowers the temperature of combustion by absorbing heat and reduces economy of operation by carrying this heat up the stack. These difficulties were discovered very soon after boilers were invented and attempts were made to feed the fuel to the furnace by some mechanical contrivance which was termed a stoker.

TYPES OF MECHANICAL STOKERS†

The earliest form of mechanical stoker was probably the one patented in 1785 by James Watt, the inventor of the steam engine. It was a simple device to push coal back towards the bridge, after it had been coked at the front end of the grates. It was worked intermittently by levers and was designed primarily to prevent smoke from bituminous coal.‡

The next stoker of which there is record was brought out in 1819 by Wm. Brunton, of Birmingham, England. It comprised a revolving circular grate, and a hopper with a toothed roller, placed so as to discharge the coal upon the slowly revolving grate. The device is said to have worked quite satisfactorily.

* Stoker Section, Westinghouse Electric and Manufacturing Co., East Pittsburgh, Pa.

† For a consideration of the types of mechanical stokers and data on the performance of mechanical stokers as applied to "Lancashire" or other narrow-flued boilers, see Brownlie, *Proc. Inst. Mech. Eng.*, March, **1920**, 263–428.

‡ W. R. Roney, "Mechanical Stokers," *Trans. Am. Soc. Mech. Eng.*, **12**.

Soon after, in 1822, John Stanley invented a stoker which consisted of a hopper on the front of the boiler, with crushing rollers and rapidly revolving fans for distributing the coal over the grate. Later J. G. Bodner patented, in 1834 and in 1843, a form of stoker wherein the coal was fed from a hopper on to an ingeniously designed grate in which the fire bars were slowly moved inward, and, on reaching the bridge, were dropped in sections and returned to the front of the furnace by return screws. This device, though well conceived, was complicated and too liable to get out of order to be practicable.

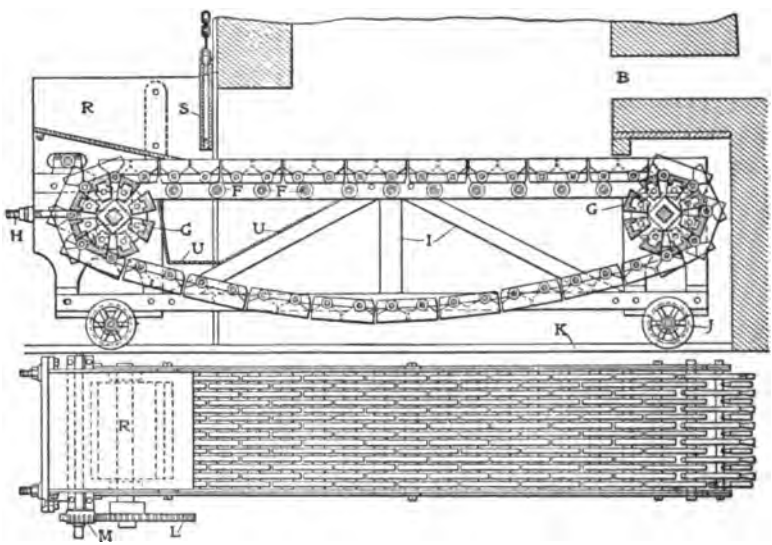


FIG. 176.—Longitudinal section and plan of the Jukes chain grate.

Prior to the year 1840, many types of stokers were patented in England, but nearly all were merely variations and modifications of the two forms of stokers patented by John Jukes in 1841 and by E. Henderson in 1843. The Jukes stoker was the first attempt at the traveling or chain-grate type and consisted of longitudinal fire-bars connected by links, so as to form an endless chain. The small coal was delivered from a hopper on the front of the boiler on to the grate which, slowly moving from front to rear, gradually advanced the fuel into the furnace and discharged the ash and clinker at the back. A large number of stokers was patented later on, all of which were along somewhat similar lines. In most of them the grate-bars extended length-

wise from front to back of the furnace, instead of crosswise, as in the Jukes stoker, and the fuel was advanced by a slow recipro-

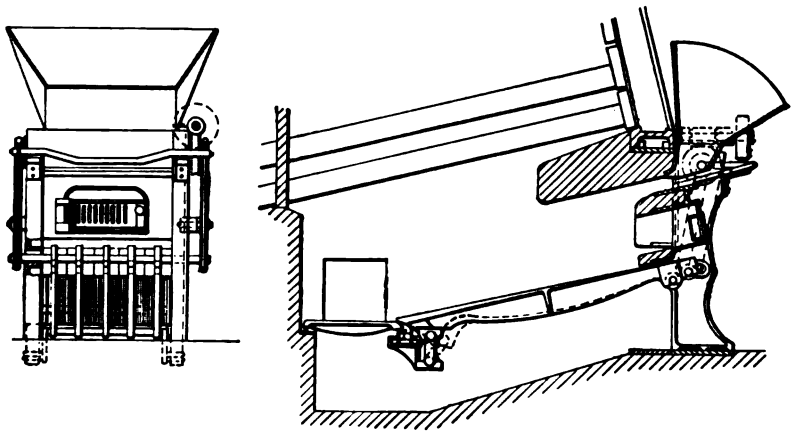


FIG. 177.—Front elevation and section of Knapp's mechanical stoker.

cating movement of the fire-bars. The most successful of this type were the Vicars' mechanical stoker, patented in 1867, and

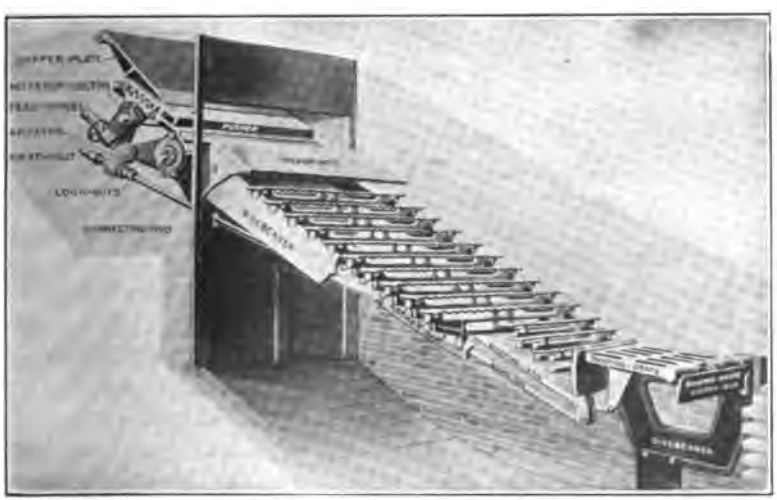


FIG. 178.—Early type of Westinghouse-Roney stoker.

Knapp's mechanical stoker, McDougall's mechanical stoker and Holroyd-Smith's mechanical stoker, all patented subsequently to 1868. The last named stoker used, instead of reciprocating

horizontal fire-bars, three longitudinal troughs placed at right angles, with another trough across the boiler front from which they received the coal. The coal was moved towards the back of the furnace by double-threaded screws, one in each trough. These screws tapered from 5 to 2½ in. in diameter and revolved at varying speeds from two revolutions per minute upward as required.*

In the class of mechanical stokers of which the Henderson is an example, the coal was scattered over the fire by revolving fans or discs or by shovels actuated by springs, which were put in tension by cams on a shaft across the front of the boiler. The

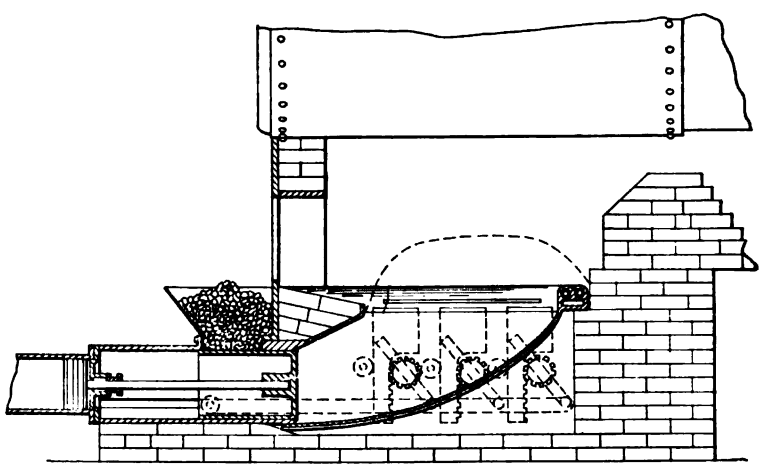


FIG. 179.—The first coal-burning Jones stoker.

other leading stokers of this type are the Bennis, the Proctor, the Hodgkinson, the Barker, and the Whittaker and Newlong, all of which were patented between 1841 and 1875.

A number of German mechanical stokers have been patented since the year 1850, but they are so similar to the English stokers that it is not worth while to mention them individually.

After 1873 there were no further important improvements in mechanical stokers until 1878, when the Murphy patent furnace was brought out in this country by Thomas Murphy, of Detroit, Mich. This furnace, which he further improved upon in 1881, by the addition of a small engine for operating it, was the first distinctively American stoker and is worthy of note

* D. K. CLARK'S "Treatise on the Steam Engine," 1, 338.

on account of its differing so radically from the English types of internal-firing stokers and because of its being adapted only to externally-fired boilers. The Murphy stoker with a few modifications and improvements has continued in use to the present day and will be described later.

In 1885, the Brightman mechanical stoker was patented by J. A. Brightman, of Cleveland, Ohio, and the same year the Roney stoker was introduced by W. R. Roney, of Chicago, Ill. The Brightman and Roney stokers are somewhat similar. In the Brightman the coal is fed in a hopper on the front of the boiler and is pushed on to the grates by a plunger working in the bottom of the hopper. The grate inclines from the inner edge of the coal hopper to the back part of the furnace at an angle of about 34°. It is composed of parallel bars extended lengthways into the furnace, with projecting overlapping shelves, and each alternate bar has a reciprocating swinging motion for the purpose of moving the fuel down the grate. The ash and clinker are drawn into the ashpit by means of a hook through an opening in the lower part of the grate, the larger masses first being broken up with a slice bar.

E. W. Jones, of Portland, Oregon, invented in 1888 the first successful underfeed type of stoker. His stoker was originally intended for use in burning wood, but later was applied to coal. It consisted essentially of a steam ram, in front of which the fuel was fed from a hopper on the front of the furnace and forced through a sort of tunnel up to the fuel bed. The fresh fuel thus was introduced from below and the volatile gases were driven off and burned first.

From 1890 up to the present day the development in stokers has been great, although no distinctly new type has been invented. The growth of very large power-houses, the desire for smoke elimination, and the increasing need of economy and conservation of coal, have, in a large measure, been responsible for this progress.

At the present time there are three general types of mechanical stokers on the market: (1) the overfeed inclined grate; (2) the traveling or chain-grate, and (3) the underfeed.

OVERFEED INCLINED GRATE STOKERS

Overfeed inclined grate stokers may be divided into two classes, based upon the direction in which the coal enters the furnace. In one class, the coal is fed from a hopper at the front

of the furnace on to grates which have an inclination of from 30 to 45° downward towards the rear. The grates form either a series of steps which reciprocate, being made to take alternately level and inclined positions, or a series of bars running from front to rear of the furnace and having an up-and-down sawing motion. By means of this agitation of the grates, the fuel as it burns is worked gradually toward the rear and bottom of the furnace. At the bottom of the grates, flat dumping sections are supplied for completing combustion and cleaning. In the second class, hoppers extend along the sides of the furnace from front to rear and the fuel from these hoppers is pushed on to the grates by a worm-conveyor feed, by gravity or by a series of plunger boxes. The grates are inclined steeply toward the center of the furnace. Here some form of clinker grinder removes the refuse. In both types the fuel is partly burned or coked on the upper portion of the grates, the volatile gases are driven off in this process, and, if perfect combustion is taking place, are ignited in their passage over the bed of burning carbon on the lower grates or on becoming mixed with the hot gases in the furnace chamber.

Overfeed Inclined Grate, Front-feed.—In the Westinghouse Roney mechanical stoker the coal is placed in a hopper at the front of the boiler. A pusher in the lower part of the hopper gradually forces the fuel over the dead plate and on to the grates by means of a slow reciprocating motion. The rate of feeding is controlled by a handwheel which lengthens or shortens the stroke of the pusher. The grate-bars extend across the furnace from side to side. All the grate bars are coupled together from underneath by a rocker bar and a variable oxcillatory motion given to this rocker bar causes the grates to rock in unison. When in an inclined position, these bars closely resemble a Dutch tile roof. This forms a fairly smooth inclined surface, upon which the coal slides slowly downward. The fuel thus is worked gradually by gravity and this motion of the grates to the lower end of the stoker. By the time it has reached the lower end, the fuel has been completely consumed and the ash is removed by dump-grates which are hand-operated from the front of the stoker. The grates are rocked forward and returned to their original position from four to six times per minute, depending upon the amount of coal which it is desired to burn per hour.

The power to operate the pusher and agitate the grates is supplied usually by a small steam engine located at the side of

the boiler, one engine generally operating several stokers. This engine drives a line shaft running along the front of the stoker just beneath the hopper. Eccentrics upon this shaft produce the grate motion, through connecting rods, to the rocker bars. The motion of the pusher is produced from this shaft by means of swinging tooth sectors, the upper ends of which engage with teeth cut in the under side of the pusher.

This type of stoker is adapted particularly to the use of coking coals and is equipped with a coking arch of firebrick sprung across the front of the furnace covering the upper part of the



FIG. 180.—Perspective view of modern Westinghouse-Roney stoker.

grate, forming a reverberatory furnace and gas producer whose action is to coke the fresh fuel as it enters and generate the gases. The construction of the front of the stoker at the arch is such that air is admitted through several small passages over the bed of burning fuel. This air mingling with the gases causes them to be consumed quickly above the bed of incandescent coke on the lower part of the grate.

The Wetzel automatic mechanical stoker differs from the Westinghouse Roney stoker in that the main grate-bars run the length of the stoker and consist of alternate moving and station-

ary bars. The moving bars rise and move forward slightly and then sink back to the level of the stationary parts. This produces a sort of sawing motion, which causes the coal to move gradually downward on the grates. The coal hopper, the coal pusher and its driving mechanism, and the dead plate, are somewhat like those of the Westinghouse Roney. Just below the dead plate is a short stationary coking grate, below which are the main shaking grates and lastly the flat dumping grates. The motion of the main grates is produced by an eccentric upon the stoker shaft, which is driven by a small steam engine located at

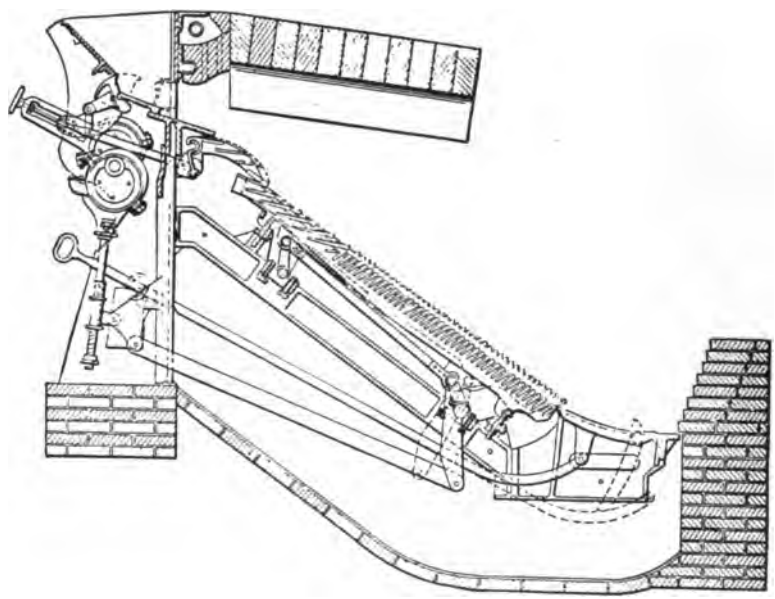


FIG. 181.—Wetzel front-feed stoker.

the side of the furnace This eccentric transmits its motion to the grates through a bell crank and connecting rod. The stoker is equipped with a coking arch which has special perforated tile in the front part for air admission to the furnace over the fuel bed. The dumping grates are operated by a hand lever from the front of the stoker.

The Lehigh mechanical stoker is a step-grate overfeed inclined grate stoker which is designed to be used for both forced and natural draft. After the coal is moved from the hopper over the dead plate into the combustion chamber by means of a

pusher, forward movement is continued by moving grates. The grate bars run crosswise of the furnace and form a series of short overlapping steps. The moving grates which alternate with fixed grates are bolted to a bearing-bar, by which motion is communicated from an eccentric shaft at the upper or outer end. The moving grates travel a definite distance horizontally, forward and back, and move in unison. The speed of the moving grates as well as that of the pusher may be varied to suit the operator or may be under automatic control by the boiler pressure. At the bottom of the main grates are the stationary flat dumping grates, which are operated by hand levers. Another special feature of

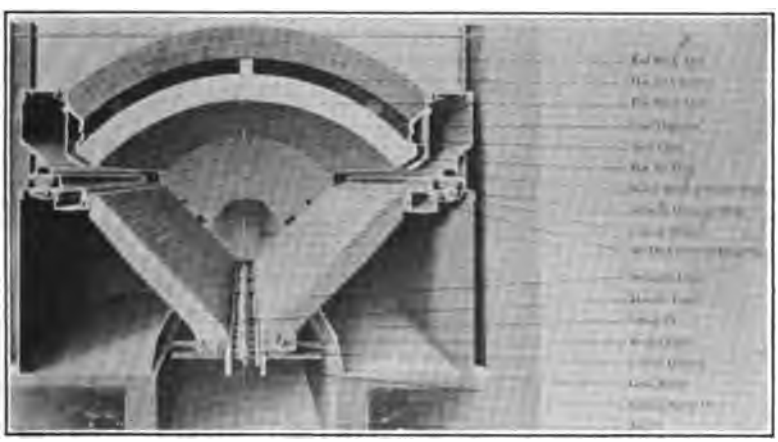


FIG. 182.—Murphy side-feed stoker (view from rear of furnace).

this stoker is that water is admitted to the bottom of each series of grates and traverses the entire length of each grate through seamless steel tubes which are cast into the grates.

There are several other makes of inclined grate overfeed stokers on the market, but they are similar to the ones described above. This type of stoker is used largely on smaller sized boilers. Where the boiler ratings demanded are not over 200 per cent, they have been used very successfully. These stokers generally are used with natural or induced draft; and, since they do not require a very deep ashpit, it is not necessary to excavate deeply below the boiler room floor. They burn nearly all kinds of coal except anthracite, and can burn this fuel if it is mixed about half-and-half with a good grade of bituminous coal. There is very little trouble with sifting of fine fuel through the grates.

When first brought out, this type of stoker was unsatisfactory, for the fuel slid rapidly down the grates and lay in a large heap upon the dumping grates. This trouble has been eliminated by making the angle of inclination of the grates well within the angle of rest of the fuel and causing movement of the fuel downward by means of motion to the grates, the amount of movement being controlled by the operator.

Overfeed Inclined Grate, Side-feed.—The Murphy mechanical stoker represents the side-feed type of inclined grate stoker. At either side of the furnace, extending from front to rear, is a coal magazine. At the bottom of the magazine are the stoker boxes, which rest upon the coking plate. These stoker boxes are operated by segment gears and racks and move forward and back. The coking plate is built up of sections into the form of a hollow box and is cooled by air passing through it. The grates are made in pairs, one fixed and the other movable. The fixed grates rest at their upper end against the coking plate, while the lower end is supported by the grate-bearer. The movable grates, pivoted at the upper ends, are moved by a rocker-bar (located at their lower ends), alternately above and below the surface of the stationary grate.

As the coal leaves the magazine from which it is fed alternately and intermittently, it rests for a short time upon the coking plate. The fuel then travels slowly down the inclined grates, burning as it goes, so that, by the time it has reached the bottom, complete combustion has taken place, and the refuse is removed by the clinker grinder. The clinker grinder consists of a steel shaft on to which are slipped toothed cast-iron segments. It has a revolving motion and is actuated by the reciprocating bar across the stoker front. The clinker grinder is carried by the grate-bearer, which also acts as a support for the lower end of the stationary grate-bars. Just below the clinker grinder is a perforated pipe, through which the exhaust steam from the stoker engines is run at intervals to soften the clinker and assist in the cleaning process. A triple arch is sprung over the entire surface. The lower arch is of firebrick, above which is an air space of from 3½ to 5 in., with a double common-brick arch above. Air is conducted to this space by the hollow coking plates which connect with it at the rear end. This heated air then is admitted to the fire through perforated arch plates just over the coal throat opening. This air mingles with the volatile gases expelled from

the coal on the coking plates and the mixture is consumed in the combustion chamber. The furnace is actuated by a reciprocating bar extending across the furnace front and to it the working parts are attached by links which may be adjusted or removed at will by the operator. By this means any moving parts, such as clinker grinder, grates, or stoker boxes, can run faster or slower as required, irrespective of the movement of the rest. A small steam engine or a motor mounted at the side furnishes the power for the actuation.

The Detroit stoker is very similar to the Murphy. It also is equipped with a coal magazine on either side, running from front

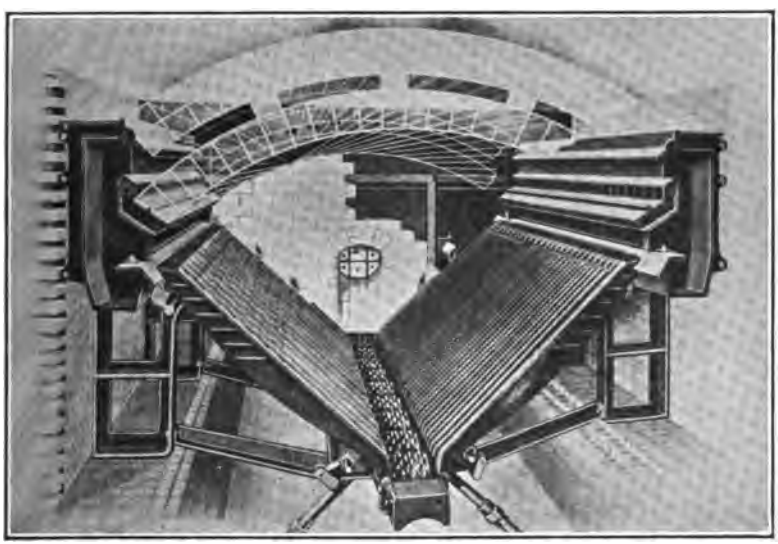


FIG. 183.—Detroit side-feed stoker.

to rear, with pusher boxes, coking plates, alternate moving and stationary grates, and a clinker grinder. For small installations, especially in cases where the coal is shoveled from the floor into the hopper, also when it is desirable to use a flush front setting, a worm coal-conveyor is used instead of the pusher boxes for feeding in the coal. In this method a worm conveyor runs along either side of the furnace where the coal magazine would normally be placed. A small hopper is placed at either side on the front of the furnace, and the coal is carried back and fed into the furnace from this hopper by the worm conveyor. These coal conveyors are front-end thrust ball-bearing and are operated from

the front at a slow speed; they distribute the coal evenly upon the coking plates.

The reciprocating feed on the Detroit is very similar to the feeding mechanism on the Murphy and the power is supplied by a small steam engine or motor located at the side of the furnace. The clinker grinder in this stoker consists of a row of short cast-iron rolls, knobbed on the outside. These are set in the grate-bearer with their axes parallel to the front of the stoker, and roll alternately towards and from each other. This motion is produced through cranks by a shaft, which is driven from the front of the furnaces. The Detroit usually is supplied with an arch similar to that of the Murphy, but sometimes is equipped with a flat suspended arch.

This type of stoker also is represented by the Model Automatic Furnace, which is, however, very similar to the Murphy stoker. These stokers can be applied satisfactorily to nearly all classes and sizes of boilers, but are not able to derive successfully more than 200 per cent rating. They burn all grades of bituminous and semi-lignitic coals, but cannot burn anthracite. They do not need a very deep ashpit and hence it is not usually necessary to excavate a deep cellar. The ashes can be removed either from a pit in the boiler-room floor or from the basement into cars.

TRAVELING OR CHAIN-GRATE STOKERS

There are several makes of chain-grate stokers on the market, but they are very much alike and all are developments of the type brought out by Jukes in 1841. The chain-grate stoker consists of short narrow horizontal fire-bars assembled on cross-rods to form a reasonably flexible endless-chain belt. This belt, which has nearly the same width as the furnace, runs over rollers set in a frame which extends the length of the furnace. It is actuated by a sprocket or sprockets, mounted upon a shaft at the front of the stoker and engaging with some of the links or small rollers upon the cross-rods. The coal is delivered to the grate from a hopper on the upper part of the furnace. The grate, in carrying the coal into the furnace, first passes under an adjustable apron which regulates the thickness of the coal upon the grate. The grate moves slowly from front to rear, gradually advancing the fuel into the furnace where it is burned and then discharging the ash and clinker at the rear.

The frame work which supports the chain consists of heavy cast-iron sides, held together by rods and maintained rigid by diagonal braces. The frame usually is mounted on flanged wheels to fit "T" rails, so that the stoker can be withdrawn easily from the furnace for inspection or repairs. The stokers are built with the grate surface either horizontal or inclined downward toward the rear of the grate. The driving mechanism consists of a worm-gear operated by means of a pawl and ratchet wheel, driven by an eccentric which is fastened to a line shaft, either overhead or underneath, according to the method of installation employed. This gear drives the shaft upon which the sprockets

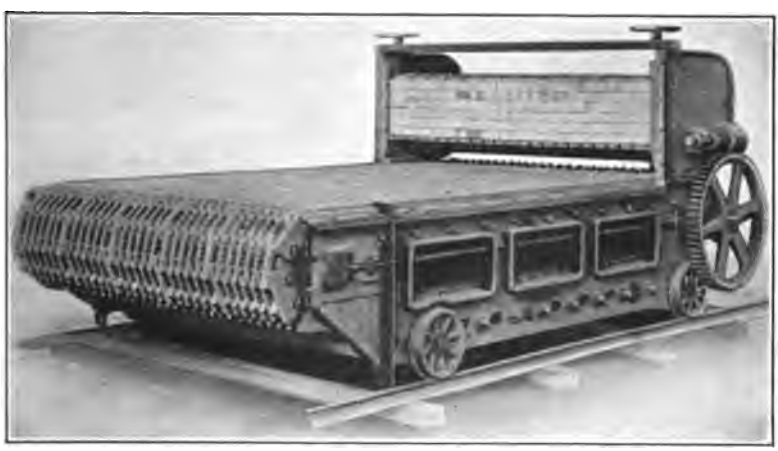


FIG. 184.—Perspective view of Westinghouse chain-grate stoker.

are mounted. The front sprockets are keyed to the shaft and drive the grates, while the rear sprockets are idlers and turn loosely between collars on the fixed rear sprocket bar. The power required is furnished to the line shaft from some outside source. The speed of travel of the grate is regulated by a lever which controls the number of teeth on the ratchet wheel that the pawl engages at each stroke. The thickness of the fuel bed and the speed of the grates are regulated so that the fuel is consumed completely by the time it reaches the rear of the furnace, and only the ashes and clinkers are dumped off into the ash pit.

The grate bars usually are made so that there are numerous small openings between the links for the purpose of admitting air uniformly under the fuel bed. With chain-grate stokers there is

apt to be considerable leakage of air past the sides of the stoker and through the ends. Careful construction and setting will largely overcome leakage past the sides, while there is customarily some special construction to prevent leakage at the ends. At the rear a hipped or overhung bridgewall is provided, so that it forms a seal with the ashes on the grates. This bridgewall sometimes is furnished with a water pipe for cooling purposes. Just in front of the rear sprockets, and within the belt, a vertical baffle wall is built, extending across the furnace and equipped with a seal at the top which fills with ashes. A metal plate riding on the upper surface of the lower chain provides the seal at the bottom. This baffle prevents the passage of air through the rear end of the chain where the links open up as they turn around the rear sprockets. Chain-grate stokers usually are installed with a firebrick arch over the front part; this is sometimes a sprung arch and occasionally a suspended one.

The Green Engineering Co., the Illinois Stoker Co., the Babcock & Wilcox Co., the Laclede Christy Clay Products Co., the Cox-Fulton Co., and the Westinghouse Electric & Mfg. Co. are some of the principal manufacturers of chain-grate stokers.

Chain-grate stokers are used both with natural and forced draft, although their use with forced draft is a recent development. They have been applied extensively in the past, but the more recent underfeeds are replacing them rapidly. They are comparatively slow steamers and are not able to develop very high capacities. They can burn all grades of bituminous coal, provided the coal is fairly uniform. They require very careful attention in order to prevent their dumping an excessive amount of combustible matter into the ash pit.

UNDERFEED STOKERS

Underfeed stokers may be divided into two general classes. The first class has as a usual thing one plunger and underfeed section to a furnace, and all coal is pushed up through the center of the furnace and gradually works to the side where the ash is dumped. In the second class the coal is fed in upon the grates from several plungers placed across the front of the furnace. The grates slope slightly toward the rear of the furnace, and the ash and clinker are dumped at the rear. Underfeed stokers of both classes use forced draft and are supplied with forced draft equipment.

Side-dumping Underfeed Stokers.—The Jones standard stoker is a good example of the first class. The coal is fed into a small hopper, which is just above the floor and in front at the center of the boiler setting. From the lower part of the hopper

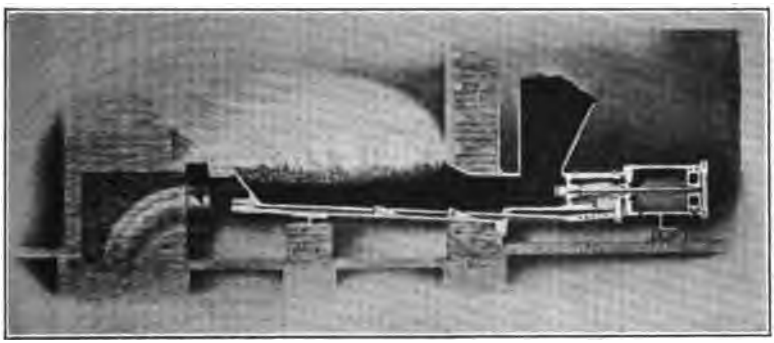


FIG. 185.—Longitudinal section through the Jones standard underfeed-stoker.

it is forced into and along a retort by a ram-plunger operated by steam. Admission of steam to the cylinder is controlled by the movement of a hand-lever or by operation of the automatic attachment. The movement of the main ram is assisted in

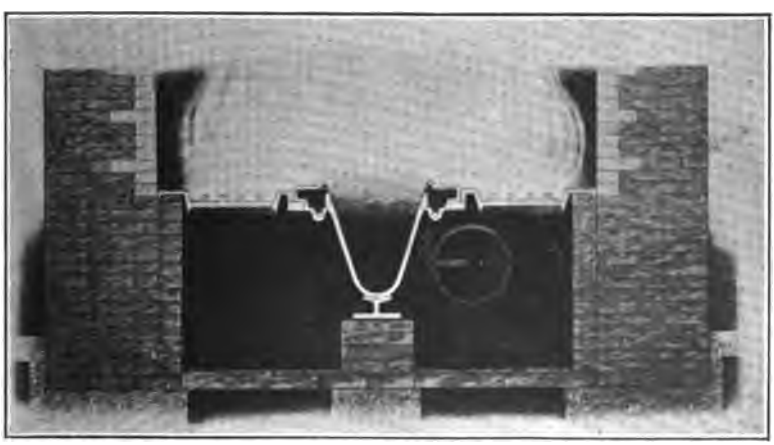


FIG. 186.—Cross-section through the Jones standard underfeed-stoker.

moving the coal forward into the retort by secondary small plungers in the bottom of the retort which move forward in conjunction with the main ram.

The retort is a narrow trough, extending from the front

wall to a point just a little in front of the bridge-wall of the furnace. Each forward movement of the ram carries 15 or 20 lb. of coal into the furnace and this operation, in conjunction with the movement of the auxiliary plunger, causes the fresh fuel to be forced up into the fuel bed from below and gives an upward and backward movement to the entire fuel bed, thereby breaking the fire at each charge. The fuel bed piles up in the retort and fresh charges cause it to spread over the dead plates on both sides of the retort toward the sides of the furnace. The ash

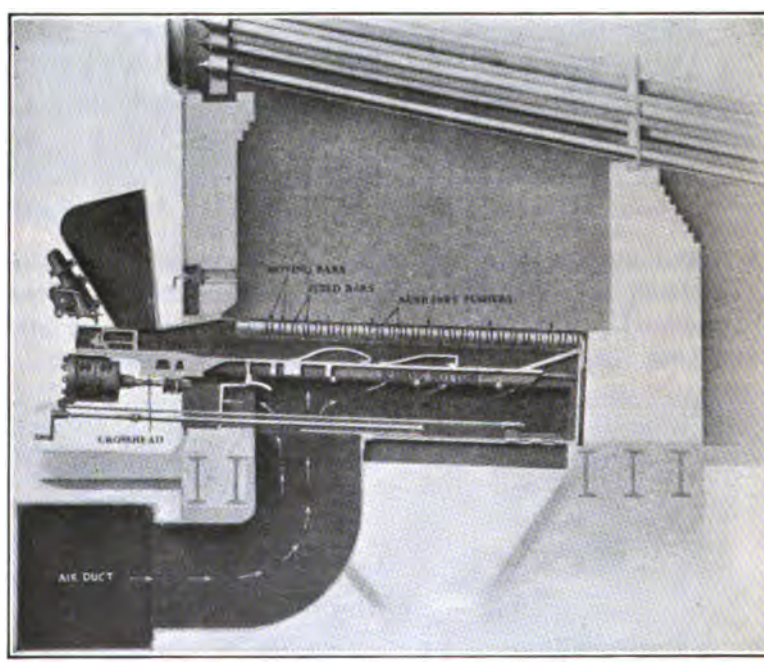


FIG. 187.—Longitudinal section through the center of the retort of a type "E" stoker.

and clinker are dumped by flat-side dumping grates into ash pits below. The pieces which compose the upper edge of the retort are sectional, cast hollow and pierced with air-admission openings. These pieces, or tuyeres, are connected with an air chamber below, and air for proper combustion of the fuel is admitted through these openings. The tuyeres are constructed so that their removal or replacement is comparatively easy.

The air required for combustion is furnished by a volume blower driven by an independent engine or electric motor, or by

connection to a line shaft. Air ducts conduct the air from the blower to the air chamber below the tuyeres and are equipped with gates or valves for controlling volume and pressure. Both the rate of feeding fuel and the air requirements may be regulated automatically. Where equipped with the automatic device, the fuel and air supply is proportioned and regulated by the steam requirements. In cases of very wide furnaces there are sometimes more than one retort per furnace.

The type *E* stoker manufactured by the Combustion Engineering Corporation is somewhat like the Jones. In the type *E* stoker the coal is fed into a hopper in front at the center of the boiler and is conveyed under the fire by means of a reciprocating feeder-block working in the bottom of the hopper and also by a reciprocating sliding bottom of the feed trough or retort which runs the full length of the stoker. The sliding bottom is driven by a steam piston, the cylinder of which is bolted to the stoker-frame under the hopper. The movement of this piston is transmitted to the sliding bottom through a crosshead, which is bolted rigidly to the sliding bottom, the piston driving the crosshead through a sleeve on the piston rod, fitting loosely in a yoke on the underside of the crosshead. The feeder block is fastened to the sliding bottom and forces the coal on to it. This sliding bottom has auxiliary pushers on it which tend to carry the coal the full length of the retort and at the same time push it upward into the fuel bed.

As the coal rises in the retort it is flooded on to transverse grate-bars, which extend from the edges of the retort, slanting down towards the sides of the furnace. The grate-bars are arranged in pairs, alternately fixed and moving. The motion of the moving bars is horizontal at the inner or retort end and slightly inclined at the outer end, the extent of the motion being about 1 in. This motion slowly works the coal as it burns from the retort toward the sides of the furnace, where it drops on to flat dumping trays and is dumped when complete combustion has taken place. These trays are dumped by a hand-operated dump-lever located at the front of the furnace. The motion of the moving fire-bars is obtained through the agency of two helices and nuts located outside the furnace. The helix nuts are bolted to the crosshead and reciprocate with it, causing the helices to rock to-and-fro, and with them the rocking bars. On the upper side of the rocking bars is a rib

which engages between two lugs cast on the underside of the moving fire-bars. The motion of the rocking bars thus causes the moving fire-bars to move outward and inward with each stroke of the piston.

Air for supporting combustion is supplied by a separately driven blower or fan connected to the stoker windbox by a pipe or duct. After entering the windbox, the air passes upward along each side of the retort and is discharged into auxiliary air boxes. From these chambers the air enters the fire through narrow openings between the fire-bars. Provision also is made to admit forced draft under the dump trays when necessary. Automatic regulation of both coal and air is provided for, if desired, by a regulator which is sensitive to variations of steam pressure. By means of connections from this regulator to valves of the blower engine (or rheostat on a motor) and the stoker controlling valves, the amounts of air and coal used are increased or decreased as steam pressure decreases or increases, so that a uniform pressure is maintained. In extremely wide furnaces there are two retorts per furnace, but only one retort is used with widths up to 13 ft.

The principles of operation and the mechanical construction of the Roach underfeed stoker are almost identical with those of type *E*. The only apparent difference seems to be that the grate bars, both moving and dead, are not cast hollow, as in type *E*, but are of the open bottom construction, having short overlapping plates with air-admission openings between them. The air is conducted to the tuyeres and air openings in the grates by means of a main windbox and side air chambers, as in type *E*.

The Moloch stoker is of a slightly different design. The coal is fed into a retort in the furnace by a steam-operated ram in much the same manner as described for previous stokers. A pusher-rod extending beyond this ram is equipped with blocks, which tend to carry coal the full length of the retort as well as force it upward into the fuel bed from below. The edges of the retorts are lined with tuyeres containing perforated air-admission openings. There is one retort to about every 200 hp. of the boiler, so that large size boilers have several retorts. There are no grates between the retorts, but simply downward slanting dead plates with a rotary clinker grinder at the bottom. These clinker grinders alternate with the retorts, so that there is a clinker grinder on both sides of each retort. Forced draft is used, and

regulation of both fuel and air supply can be controlled by the load demands, actuated by the boiler pressure.

The Stevens underfeed stoker is a design with a screwfeed. This stoker comprises a retort, or series of retorts, open at the top and extending from a short distance outside the front of the boiler to the rear of the furnace. A removable hopper is fitted to the outer of these fuel retorts, with observation and leveling doors in the stoker front above the fuel hopper. In the bottom of each fuel retort is an intermittent screw conveyor, which feeds the coal into the furnace from the hopper.

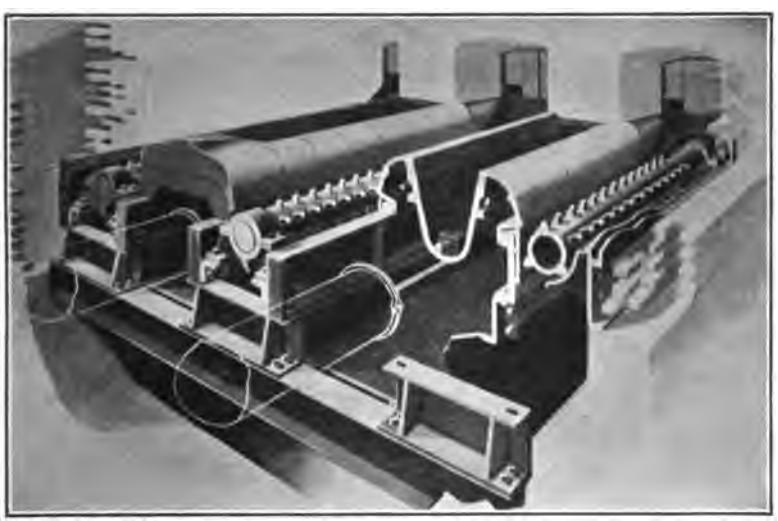


FIG. 188.—Moloch underfeed-stoker. Sectional perspective of a two-retort equipment. The view is taken from the rear of the furnace.

Rocking and dumping grates are placed on each side of and level with the fuel retorts. The grates between any two retorts are connected to form a section which is controlled independently by the operator. Running across the front of the boiler or boilers, parallel to the front setting, is a line shaft which is driven by a variable-speed electric motor or independent steam engine connected through a gear reduction. Running loose on this main shaft at the outer end of each fuel retort is a steel cut worm contained in an oil-tight gear box with suitable thrust bearings. This worm meshes with a bronze wormwheel operating the coal conveyor in the retort. Clutches are placed on the main shaft between fuel retorts, and these clutches, when thrown into engage-

ment with the worm, give individual control of each unit. Forced draft is supplied by a turbine undergrate blower that is installed between the ashpit doors, in the lower section of the boiler front under the fuel retorts. The edges of the retorts have a series of openings which admit air to the fuel bed. Openings between the grate-bars also admit air to the fuel bed, since the ashpit acts as a windbox.

In the American Stoker Co.'s worm-feed stoker the screw conveyor carries the coal from the hopper in front of the boiler into the retort. The rear end of the retort curves upward and the fuel thus is forced upward into the fuel bed. The fuel overflows

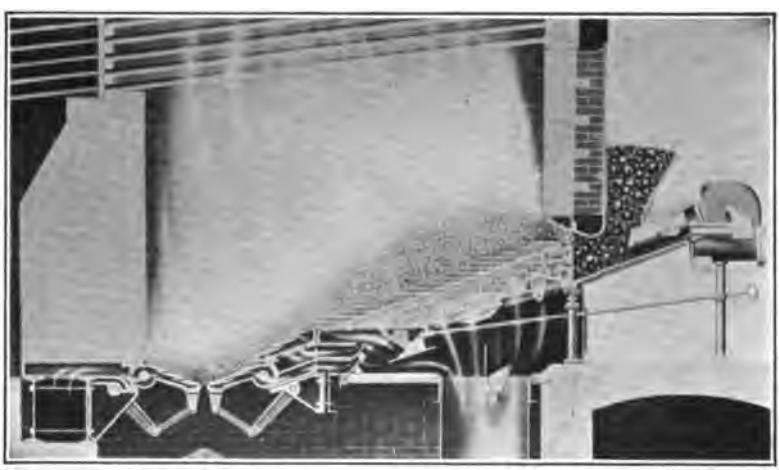


FIG. 189.—Longitudinal section of the Westinghouse standard multiple-retort underfeed-stoker.

from the retort on both sides on to flat side grates. It is cleaned by hand through front fire-doors. Air is introduced into the furnace through tuyeres which line the retort sides and which connect with a windbox located below the retort. The air is supplied by a blower-fan and is conducted through suitable ducts to this windbox. The stoker is driven by an eccentric upon an overhead shaft operating through a connecting rod upon suitable mechanism, which, in turn, operates the screw.

Underfeed stokers of the types described above have been used quite extensively in recent years on small boilers and small size units. The hopper usually is filled by shoveling the coal from the floor, and the ashes are removed from a pit by

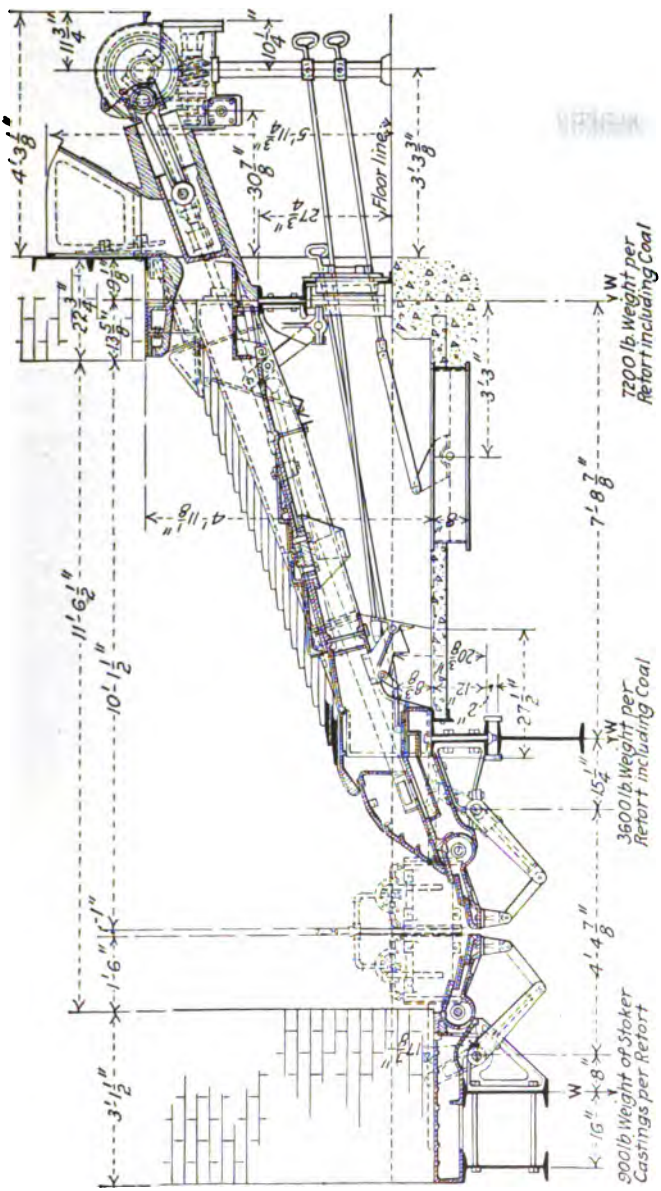


FIG. 190.—Longitudinal section of Westinghouse long stoker with steam-power dump.

raking them on to the boiler-room floor and then removing them, so that labor costs are not reduced much by use of the stoker. They are able to carry sudden overload successfully, provided they are not over 200 or 225 per cent boiler rating, and, in general, require little attention.

INCLINED-GRATE UNDERFEED STOKERS

The multiple-retort inclined-grate underfeed type of stoker is one of the more recent developments in mechanical stokers. There are at present several makes on the market, prominent among which are the Westinghouse Underfeed, the Riley Self-dumping Underfeed, and the Taylor stoker.

In the Westinghouse Underfeed stoker the coal is placed in a hopper which extends completely across the front of the furnace. At uniformly spaced intervals underneath the hoppers are cylinders, inclined slightly downward, in which operate plungers. There are ordinarily one cylinder and plunger for each rated 100 hp. of the boiler. These plungers, assisted by gravity, push the coal into the retorts inside the furnace. A deflecting plate in the upper part of each retort directs the fresh fuel upward into the fuel bed.

Alternating with the retorts are the tuyere boxes. These are hollow box-like structures and are so shaped that, while they slant downward at the same angle as the retorts, the tuyeres are arranged to form a series of short, horizontal, overlapping steps with air-openings in the vertical faces. The tuyeres themselves are small semi-circular iron plates, corrugated at their outer ends to form the air openings. They are held rigidly in place by interlocking with each other and hooking into recesses in the tuyere boxes. In the lower part of each retort a series of overlapping pusher-blocks keep the burning fuel gradually moving toward the lower part of the stoker. The fuel, after being pushed into the retort by the main plunger or ram, is partially deflected upward by the deflecting plate and partially moved down the retort and spread over the lower part of the grates by the secondary pushers. In this way a fuel bed is formed over the entire stoker, which is thick at the upper end and thinner at the lower or rear end. It is supplied with fresh fuel from below by the retorts and with air from below through the tuyere openings. Toward the lower end of the stokers the tuyeres and retorts terminate in a short fixed section running across the

width of the stoker and known as the coal extension plate. Below the coal extension plate is an overfeed section which has a reciprocating motion which further assists combustion of the fuel, moving it downward toward the furnace bridge wall on to the dumping grates at the extreme lower end of the stoker. From here the ash is dumped into the ashpit below, after the combustible matter in the ash is completely consumed.

The coal extension plates, the overfeed section, and the dump grates are made of overlapping plates with air openings in the vertical faces and are connected to the wind-box so that air can be admitted to the fuel bed through them at any time by

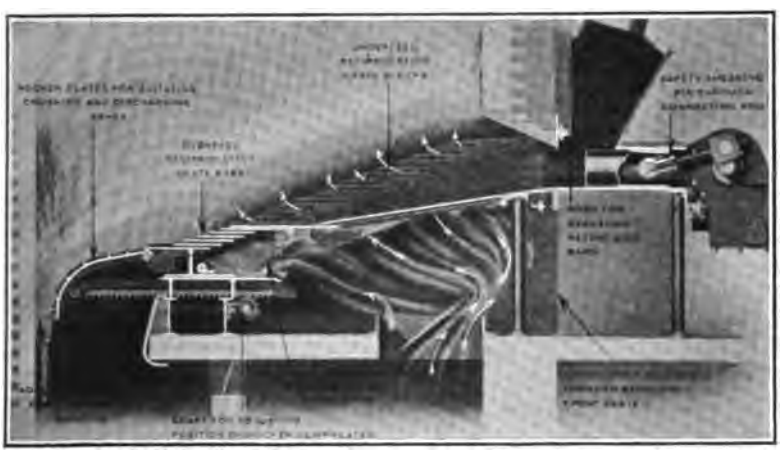


FIG. 191.—Longitudinal section through the Riley multiple-retort underfeed-stoker.

adjusting dampers provided for the purpose. Double dumping grates are included. The forward dump grate is hinged just below the overfeed section and projects toward the bridge wall. The rear dump grate is hinged at the bridge wall and projects toward the front of the stoker. Both dump grates are operated from the side of the stoker by a worm and sector operated by a ratchet lever. In case a power dump is wanted, a steam cylinder or an electric motor, equipped with suitable mechanism, can be used.

Air for forced draft is supplied by a fan or blower driven by a small turbine or motor and is connected by ducts or pipes to the stoker wind-boxes. The main wind-box is located just beneath the grates. The tuyere boxes, the overfeed section, and the

forward section of the dump grates, all have openings into this wind-box. These openings are equipped with dampers operated from the front of the stoker, so that the amount of air admitted to any section of the grates is controlled completely. An auxiliary wind-box, located under the bridge-wall, supplies air to the rear dump-grate. Above the upper end of the tuyere boxes and extending laterally across the furnace are air-distributing boxes which have an air connection with the top of the tuyere boxes. These distributing boxes admit air above the fire for the purpose of completing the combustion of the gases distilled from the coal in the retorts.

Power to drive the stoker is supplied by a small steam engine or electric motor, located at one side of the boiler or battery of



FIG. 192.—Riley self-dumping underfeed-stoker. Perspective view of a nine-retort stoker partially assembled, showing independence of unit parts.

boilers, and is transmitted to a line shafting running across the front of the stoker. From the line shaft, through bronze and steel reduction gears enclosed in a gear-case, power is transmitted to cast-steel crankshafts on the front of the stoker. Connecting rods upon these crankshafts actuate the main plungers and these main plungers in turn actuate, through lost motion mechanism and connecting rods, the lower pusher-blocks and overfeed section.

The Riley Self-dumping Underfeed stoker operates quite differently from the Westinghouse. This stoker has one ram-plunger or coal pusher for each retort arranged horizontally and the retort bottom does not have as much slope downward as the grates. The air-supplying grates and overfeed sections have a reciprocating motion to assist in working the coal downward toward the lower end of the furnace. The air-supplying grates and

retorts terminate at the reciprocating overfeed section, which has the same amount of motion as the air-supplying grates. Another features are the dumping grates. These are made up of overlapping plates, hinged together so as to form an apron which hangs down over the ends of an adjustable rack. This rack can be controlled by a handwheel located at the side of the furnace and can be set for any size opening needed. The dump-grate is hinged to the overfeed section at the upper end and runs over rollers in the rack at the lower end, so that it has a combination of vertical and horizontal motion which agitates, crushes and

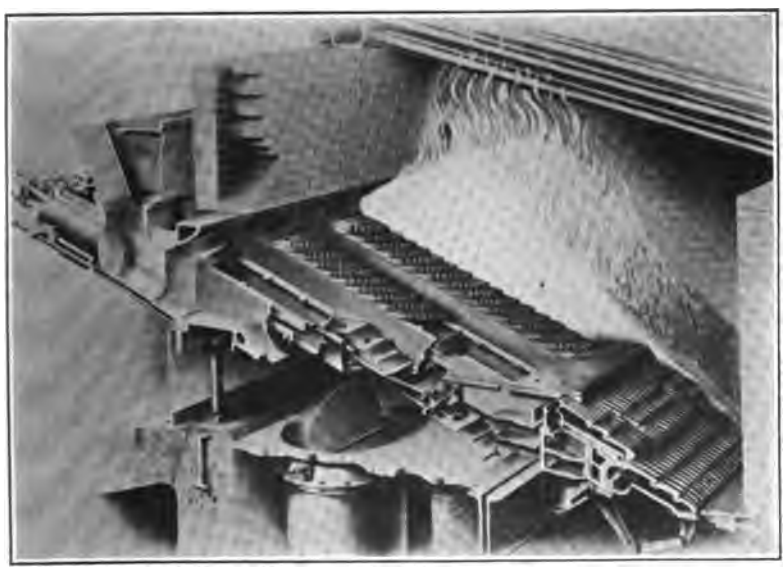


FIG. 193.—Perspective view of the Westinghouse multiple-retort underfeed-stoker.

ejects the ash into the ashpit below. Fans are used for supplying air under pressure to the stoker and the auxiliary mechanism for driving the stoker is very much like that used with the Westinghouse stoker.

The Taylor stoker differs from the Westinghouse and Riley underfeed stokers in that, instead of using auxiliary pusher blocks in the lower part of each retort, secondary rams are employed. There are two of these secondary rams in the very large size stokers, while only one is used in the smaller sizes.

Coal from the hopper is fed into the retort from which the

upper rams, assisted by gravity, introduce it into the furnace at an angle to the fire surface. Movement of the upper ram pushes the green coal outward and upward, distributing it in the coking zone. The action of the lower ram is similar, but instead of bringing in the fresh coal it pushes the fuel bed and refuse toward the dump plates at the rear. The retorts and tuyere boxes alternate the same as in the Westinghouse and Riley, and the number depends on the size of the boiler to which the stoker is to be applied. A series of tuyeres is supported on each tuyere box, with openings in the vertical faces to distribute air to

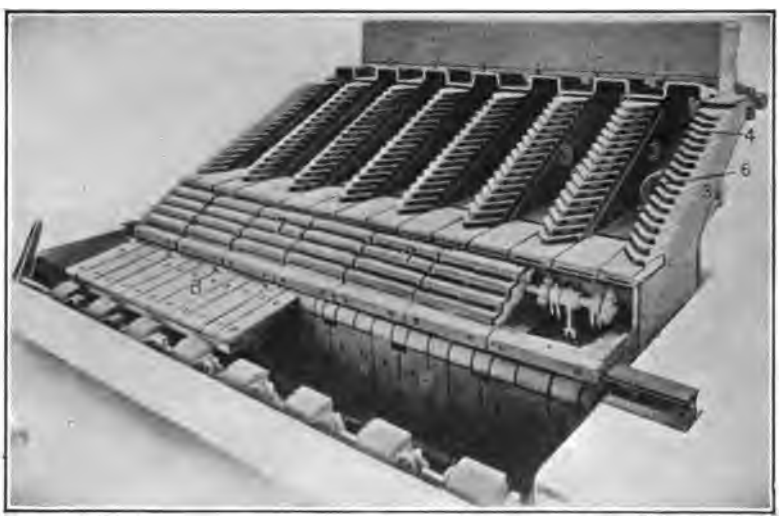


FIG. 194.—Perspective view of the Taylor two-ram stoker.

the fuel bed. Air for combustion is furnished by a fan or blower driven by a steam engine, turbine or motor, and is conducted by ducts to the wind-box just below the grates. From the wind-box it enters the tuyere boxes and passes through the tuyere openings to the fuel bed. The rams are actuated by connecting rods and links from a crank-shaft which receives its power from the speed-shaft through reduction gears enclosed in a suitable gear-box. The speed-shaft in turn may be driven by the fan prime mover or from a line shaft driven by a small steam engine or electric motor.

The dump-grates, which are combination dump-grates and fire guards, are hung on the rear of the wind-box and project

toward the bridge wall. These plates receive the burned-out refuse and are dumped periodically. The dump plates are operated from the front of the stoker, raised, latched in position, and released by a hand lever. In some cases power-dumping apparatus is furnished, which consists of a steam cylinder and suitable mechanism; this is located just beneath the wind-box and is operated by a level at the side of the furnace. Where the

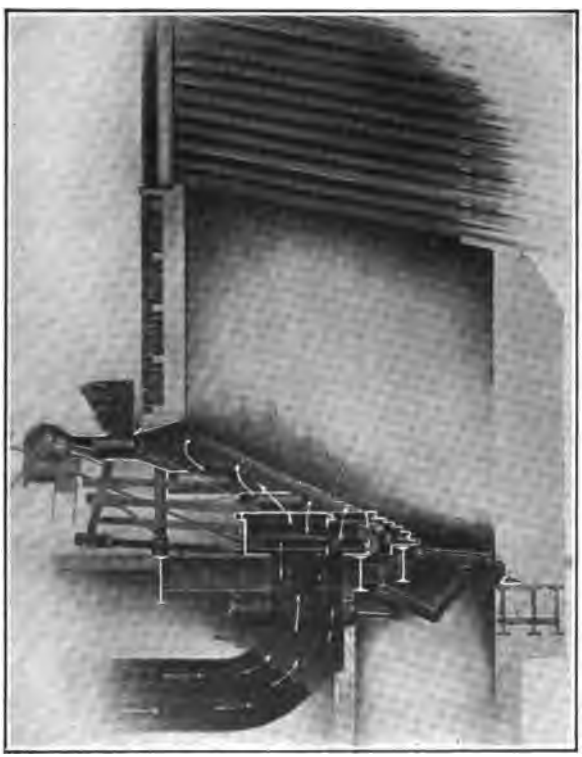


FIG. 195.—Longitudinal section through the Taylor three-ram stoker.

stoker is equipped with extension grates, which lie between the mouth of the retorts and the dump plates, they serve as active grate surface or for ash storage as required. These grates are connected with the operating mechanism in such a manner that they may be rocked in sections subject to adjustment. The air supply to the wind-box and to parts of the grates is controlled by dampers which may be operated from in front of the stoker.

The three types of underfeed stokers described above are

very quick to respond to high overload requirements and well able to take care of variable loads. They are capable of producing almost any rating within the limit of the boilers and ratings as high as 500 per cent normal boiler ratings have been obtained for short intervals. The fuel and air supplies may be varied automatically to suit load conditions, by employing a suitable regulating mechanism which ordinarily is controlled by variation in the steam pressure.

ADVANTAGES OF STOKERS

The advantages gained by the use of stokers is best expressed by quoting from the treatise on "Heat Engines" by Allen and Bursley, as follows:—

"One of the most apparent advantages in the use of mechanical stokers is the saving in the fire-room labor. This is particularly true in large plants and where coal-handling and ash-handling machinery is used. Stokers may save as much as 30 to 40 per cent of the labor in large plants; that is, plants using over 200 tons of coal per week. In plants of medium size, those using from 50 to 150 tons of coal per week, the saving in labor may amount to from 20 to 30 per cent. In small plants there is not likely to be a saving in labor.

"Another advantage of stokers is that they permit the use of a cheaper grade of fuel than could be used with hand-firing, since they carry a cleaner fire, the coal is fed more uniformly, and the air required for combustion is supplied at a fixed and constant rate.

"Even if no saving can be effected by using a cheaper grade of coal, it may still be advisable to use a stoker to lessen the smoke. With cheap fuel it is almost impossible to prevent smoke when such fuel is hand-fired, but with a stoker of the proper design and properly operated the amount of smoke given off may be negligible. However, in practice, stokers are sometimes not properly operated and under such conditions may give off as much smoke as a hand-fired furnace.

"Boilers equipped with stokers can be made to produce much higher ratings with stokers than with hand-fired furnaces, as the rate of combustion per square foot of grate area is much higher and the air supply constant. With hand-fired furnaces the air supply varies considerably, due to the intermittent opening of the firing doors. Stokers also produce greater uniformity of furnace conditions and steam pressure than hand-fired furnaces."

CHAPTER X

THE USE OF WOOD FOR FUEL*

Heretofore wood has supplied between 10 and 15 per cent of the total amount of fuel used in the United States. The South normally uses a large proportion of wood. Long rail hauls are involved in utilizing wood in the West, and its use for fuel cannot be greatly increased there. But in New England, New York, New Jersey, Pennsylvania, Ohio, Indiana, Iowa, Missouri, and the Lake states it is practicable to replace coal with wood to a considerable extent. For many uses, and particularly for summer-time use, wood is a more convenient and cheaper fuel than coal. For churches, halls, summer cottages, and other buildings where heat is wanted only occasionally, and then on short notice, wood is more satisfactory.

In utilizing the forests of the country, including farm woodlands, a great deal of wood material is produced which cannot find use other than as fuel. Many of the trees of our forests, also, are fit only for fuel; but improvement cuttings, which take the small diseased or defective trees, can be profitably made only where there is an actual demand for fuel wood. These thinnings and improvement cuttings stimulate increased production and improve the quality of the timber; and thus a demand for fuel wood opens up a great opportunity for forest improvement. Furthermore, the wide use of wood for fuel affords a market for the waste that occurs at every stage of the manufacture of wood products. Preparing wood for fuel involves slightly more labor than is required to produce coal, but it is usually widely scattered labor and in winter on most farms there is plenty of time for men and teams to work at getting out wood.

THE INDUSTRIAL USE OF WOOD FUEL

Wood is used very generally for fuel by sawmills and woodworking plants. For this purpose it is burned in the form of slabs, 4 ft. or so long, or is cut up into "hog" fuel and shoveled

* A contribution from the Forest Service, U. S. Dept. Agr., Washington, D. C.

or fed automatically into the firebox. In these cases wood fuel is a by-product which would have to be disposed of at some cost if not burned for fuel, so that its use is economical.

The use of wood for fuel by factories reached its greatest development in New England during the acute coal shortage in the winter of 1917–18. A great many factories were forced to use wood to keep in operation, and one dealer reported that he had shipped 5,500 cords to factories in eastern Massachusetts. Such use of wood will come about only through necessity, because wood costs normally three times as much as soft coal; but in wood the country has a reserve or substitute fuel and should plan wood reserves that can be drawn upon in an emergency.

WHAT TO USE FOR WOOD FUEL

Thinnings and Improvement Cuttings.—Trees that will produce lumber or other valuable material should not be cut for fuel, except in emergencies. Trees that are better suited for fuel than for any other purpose or whose removal will be of benefit to the remaining stand are the following:

1. Dead but sound trees, either standing or down.
2. Diseased and insect-infected trees, and those extremely liable to such injury, such as chestnut in the region subject to blight, or birch in the gypsy-moth area, as well as badly fire-scarred trees.
3. Crooked and large-crowned, short-boled trees which will not make lumber and which are crowding or overtopping others.
4. Trees that have been overtopped by others and their growth stunted.
5. Beech, black oak, gray birch, red maple, ironwood, or other species that are crowding more valuable ones.
6. Slow-growing trees that are crowding fast-growing species of equal value.

Trees on Old Pastures; Tops and Lops; Mill Waste.—Red cedar, gray birch, aspen, pine, and other trees, which have been allowed to steal much of the pasture land of many farms, and the uncleared corners of fields, as well as patches of agricultural land within the borders of the woodlot, may all be made to furnish fuel wood with advantage to the places where the trees have grown. The tops and limbs of trees felled in lumbering, which ordinarily rot or furnish fuel for forest fires, may provide much fuel wood at comparatively small cost, especially when the

operations are near farms. Mill waste, which is used as fuel at the plants, may also be utilized by individuals in the neighborhood of the plants.

Sawdust Briquets and Charcoal.—On the Pacific Coast, where sawdust is abundant and coal expensive, several firms manufacture briquets from sawdust. Generally a mechanical binder is used, but sometimes coal dust is mixed with the sawdust and a resinous binder used. These have the advantage of cleanliness and easy-kindling qualities. The cost of manufacture is estimated at not less than $3.00 a ton, and the briquets may compete with coal at $8.50 per ton. No kindling is required and they produce no clinkers, little ash, and no smoke.

Charcoal has a larger heating power per cubic foot than wood, and, on account of its light weight, is cheaper to transport. In 1909, Michigan, Pennsylvania, and New York produced the bulk of the charcoal made in the United States, the total product being reported as 39,017,247 bu., worth $2,351,644. It is reported that Michigan and Wisconsin now lead in its production.

There are two chief methods of producing charcoal, the old kiln method and the modern method of destructive distillation in a closed retort. Most of the commercial charcoal is still made in the kiln, the erection and operation of which costs, for the labor, about 60 cts. per ton of charcoal. Wood loses 75 per cent in weight and 50 per cent in volume in charring. One bushel of charcoal, the selling unit, weighs about 25 lb. Two cords of hardwood will yield 1 ton of charcoal.

THE SUPPLY OF FUEL WOOD

On the farms alone the total area of woodland in the United States east of the Great Plains is approximately 153,353,000 acres. An average of 10 cords per acre, which seems reasonable, would make about one and one-half billions of cords of fuel wood in this region. The woodland area is constantly shrinking, however, as a result of land clearing for agriculture and grazing, and, unless care is taken, the future supply of fuel wood will be materially reduced.

The first tier of States just west of the Mississippi has a great deal of timber, especially northern Minnesota, southern Missouri, Arkansas, Louisiana, southeastern Oklahoma, and eastern Texas. The wooded areas farther west are for the most part restricted to the mountains.

The supply of wood fuel in any locality depends not only on the total amount of timber, but also upon what percentage is on land which is suitable for agriculture and will be cleared and what percentage of that on the non-agricultural land can be cut without jeopardizing the forest resources of the future. Only by means of a survey covering these points can a practical and comprehensive plan be developed to coordinate the supply and use of wood fuel in a region with other forms of fuel.

PRODUCING AND MARKETING WOOD FUEL

Average stumpage prices for wood fuel timber range from 50 cts. to $1.50. This item may go as high as $5.00, but, on the other hand, in remote districts, where land is being cleared, standing cordwood material is sometimes given away. Slash from lumbering operations is frequently given away for the cutting or is sold at a nominal price. In many cases an owner can well afford to give material from improvement cuttings or thinnings to any one who will cut it.

Felling.—Slack times for other work on the farm are generally best for cutting wood. In the North this is usually the winter, late fall, and early spring; in the South, the summer season. Where hardwoods are to be cut and reproduction by sprouts is desired, winter felling is the best.

Cordwood is generally felled and cut into 4-ft. or sled lengths with axes or crosscut saws. Inefficient labor will produce but one-half cord of hardwood or 1 cord of softwood a day; skilled workmen will cut from 1½ to 2 cords of hardwood or from 3 to 4 cords of softwood a day. These figures include both felling the trees and cutting them into 4-ft. lengths.

Skidding and Hauling.—The general practice has been to cut wood into 4-ft. lengths, pile it near the place where the trees were cut, and haul it from there to the consumer. In many cases, however, the trees are merely trimmed or cut into sled-lengths and hauled to the consumer to be sawed into stove-lengths, or to a central point in the woodlot or along a road, to be cut up and piled for future hauling.

Sawing and Splitting.—Only in isolated cases is stove wood "bucked up" by hand with a bucksaw. A 24- or 26-in. circular saw, driven by a 6- or 12-hp. gasoline or kerosene engine which is mounted with it on a truck, and movable from place to place, is ordinarily used. Such an outfit, operated by a three-

man crew, can saw from 10 to 15 cords a day; it is often used, with exchange of labor, by the farmers of a community, or as a thrashing or silo-filling apparatus is operated. For cutting large logs up to 7 ft. in diameter, drag saws, operated by gasoline engines, are used in the Pacific Northwest. It is claimed they can cut from 10 to 30 cords of softwood in 10 hr. While splitting is still done largely by hand, often by the consumer in his spare time, splitting machines are coming into more general use in wood yards where large quantities of wood are handled. These machines are driven by the same engines that run the cutting-up saws, and sawing and splitting are done at the same time.

Seasoning.—Dry wood has a greater heating value than green and, therefore, seasoning is important. It is also more convenient to use and can be handled at less cost because of its lighter weight. Piled in open form in an open field or on a hill top, with a good circulation of air, ordinary species require from 9 to 12 months to season thoroughly, although the moisture content will be reduced to about 35 per cent in 3 months' time, in which state the wood has from 85 to 95 per cent as much fuel value as thoroughly seasoned wood of the same species.

Transportation.—Ordinarily, wood fuel is used within 5 or 10 miles of the locality where it is produced. Costs for hauling wood by team may be put at about 50 to 75 cts. a cord per mile.

As a general thing, wood fuel cannot be shipped economically by rail to market, yet in districts remote from coal regions it is sometimes practicable. Shipment by water is a cheap method, but by rail the rate for distances of about 10 miles has averaged from 50 to 60 cts. and has sometimes reached $1. Around 100 miles the rate has averaged $1.50 a cord, but has in some instances been as low as $1 and in others as high as $2. The shipping weight of a cord of wood varies greatly with the species and condition. Green red oak has been estimated at 5,800 lb. and air-dry red oak at 3,400 lb. per cord; air-dry ash, beech, birch, and sugar maple at between 3,800 and 4,000 lb.; air-dry white oak and hickory at 4,300 and 4,600 lb., respectively; and air-dry elm and red maple at 3,000 and 3,200 lb. Minimum carloads contain from 12 to 18 cords.

Methods of Selling.—Fuel wood is not transported any great distance or marketed on an extensive wholesale scale. In some communities there are regular wood dealers; but, where there

are not any, some of the woodlot owners make a house-to-house canvass with their loads and some may advertise either in the papers or by posters. Cordwood may be sold through coal or lumber dealers. A still better way is for communities to establish and control their own wood yards and provide reserves of wood fuel for winter. Municipal wood yards have been extensively tried in certain southern States; the long winters of the North make them all the more urgent there.

Measuring Wood Fuel.—A standard cord of firewood is a pile 8 by 4 by 4 ft. which contains 128 cu. ft. of stacked wood. Green wood is piled somewhat higher to allow for shrinkage. A "running" cord is 8 ft. long by 4 ft. high and 12, 16, or 24 inches wide, according to the length of the wood.

Wood is purchased for its heating value, and this depends upon its weight. But cords vary in solid volume, according to the piling, the kind of sticks, the species, etc. The actual solid content of a cord is about 70 per cent of the 128 total cubic feet in the pile. A better way to sell wood is by weight, entirely independent of species, shape or size of sticks, or method of piling, with certain standards as to time of seasoning. A pound of dry wood of one species has about the same number of heat units as a pound of any other species; so that the weight is a very good measure of the fuel value of thoroughly seasoned wood.

HOW TO USE WOOD FUEL

In order to burn wood in stoves or furnaces intended for the use of coal, it may be necessary to substitute lighter bricks in the firebox of the stove or to use shorter blocks of wood in the furnace. Beyond these, the only difficulties are in learning the adjustment of drafts, the arrangement of wood, and the methods of feeding.

The best method of firing is to keep the furnace full of wood packed close, with a moderate draft to give the desired amount of heat. As the wood burns, more should be added in order to keep the deep bed of burning fuel which is most economical.

Banking the fire at night requires an extra supply of the largest blocks and special attention to closing the dampers tight. Experience will show the best way, but it can be done with success in most furnaces.

It is not necessary to buy new grates for burning wood, although the ordinary coal grate is not well adapted for wood.

A good way is to add a little nut coal to the fire at the start, allowing the layer of coal ashes to remain on the grates. Air required for combustion can pass through the ash layer, which can be shaken lightly without much loss of ashes. The larger the firebox the better the results.

The simplest way to use wood in a coal furnace, and the most effective in producing heat, is to combine it with coal. The method of firing is to place blocks of wood on the fire to about the level of the fire door, instead of shoveling on coal in the usual way, then to add coal on top. A fuel charge of this kind will produce good heat, but will not last as long as a fire-pot full of coal; hence more frequent attention is needed.

The secret of fireplace management is a plentiful supply of ashes kept at the level of the andirons. As the blocks burn, an accumulation of glowing charcoal forms in the ashes and this burns slowly and assists the ignition of the fresh blocks. To check the fire or to keep it for the night, ashes may be shoveled over one or more of the blocks. A banked fire will keep for 10 or 12 hr., and will send some heat from the hot bricks all the time.

THE EFFICIENCY OF WOOD FUEL

Theoretical Heating Values of Wood.—The heating value of a given volume of dry wood is in direct ratio to its specific gravity. In theory, equal weights of wood substance give off the same amount of heat, regardless of species. In reality, the varying forms of tissue and the presence of resins, gums, tannin, oils, and pigments, as well as water in varying amounts, cause different heating values. Rosin may increase the heating value 12 per cent or more. On the basis of weight, wood is about 57 per cent as efficient as coal.

Under the most favorable circumstances, the heating efficiency of 1 lb. of wood containing 25 per cent of moisture will be about 72 per cent of that of a pound of dry wood. On the other hand, the pound of wet wood dried out absolutely, so that it weighs ¾ lb., will have an increase in heating value of only about 5 per cent due to drying. Although green wood is heavier and slower to ignite, for a slow fire it alone or in combination with dry wood is often more satisfactory than dry wood alone. Heating values of different parts of the same tree may vary considerably because of differences in moisture content, pro-

portion of bark to wood, and other factors. Softwoods burn more readily than the hardwoods and the lighter hardwoods than the heavier ones. A cord of hardwood will make only about 60 lb. of ashes, but a ton of hard coal will make from 200 to 300 lb. During the winter of 1917–18, it was found in a factory that, for steam production, 1 ton of green hardwood was equal to 0.7 ton of soft coal. Careful tests in Georgia showed that, to keep a room at a comfortable temperature with an open hearth fireplace, nearly 10 times as much wood must be consumed as when a stove was used.

WOOD FUEL FOR THE FUTURE

Growing Timber for Fuel.—Timber of some species can be grown for firewood in from 10 to 15 years; but for general forest areas, and especially for hardwoods, from 20 to 50 years are required. An average of 7 cords of fuel wood an acre each year is a large yield, taking the country as a whole.

Communities in wooded regions cannot depend on chance growth of wood for their fuel supply. It is advisable and necessary that certain areas be set aside to produce wood, and that they be so managed as to produce the maximum amount of wood possible within the shortest possible time. Generally the inferior land on farms will grow sufficient fuel to supply regularly each year's needs. At any rate, fire and other destructive agents should be kept out of growing woodland; and where cutting is done for firewood, only that material should be taken out whose removal will not cause injury to the productive capacity of the remaining stand.

Fuel emergencies may be expected periodically, and the maintaining of municipal forests by cities or towns is a practical consideration. Some towns already own such tracts. Instead of being sources of expense, well-managed woodlands should quickly become sources of revenue.

PROMOTING THE USE OF WOOD FOR FUEL

Articles and advertisements in newspapers, motion pictures, illustrated talks, "cut-a-cord" clubs, "cutting bees," and posters are some of the publicity methods by which the use of wood for fuel may be promoted. In some places municipalities themselves organize wood yards to purchase, manufacture, and dis-

tribute wood fuel. Reserves of wood fuel are established in some districts where there is a possibility of a fuel shortage. For the present these reserves will probably consist largely of wood purchased from producers. Eventually, however, it may be advisable for communities to own their own woodlands in order to regulate the cutting and the price of fuel wood.

The United States Forest Service, at Washington, D. C., and the Foresters of the different States will gladly give information on this subject and furnish or suggest literature relating to it.*

* Bull. 753 of the United States Department of Agriculture, upon which this Chapter is based, is worthy of particular mention among the available Government publications. See also H. S. Taylor's "Fuel Production and Utilization," 1920, 253-80.

CHAPTER XI

FUEL OIL AND ITS UTILIZATION

By B. Stanley Nelson*

There is a distinct need for a brief elementary discussion of the principles involved in the practical application of liquid fuel to making steam in boilers, and the author feels that the limited space available for this Chapter can be utilized to best advantage by treating that side of the subject. While much of the following consideration is no doubt already familiar to engineers experienced in the science of oil burning, the idea underlying this Chapter is to make it informative to prospective users of oil fuel in boiler plants, or to persons already using plants equipped for burning oil but interested in obtaining better results. With this in mind, the author gives a number of practical details not ordinarily found in books, but nevertheless important in actual operating experience. There has purposely been omitted all theoretical or academic discussion, other than that necessary to explain the principles involved.

The parallel subject, the utilization of fuel oil direct in oil engines, is a fascinating and very important one; but the author feels that it is unnecessary to include it herein because, while the oil engine is rapidly becoming an important factor in power production, the details and results from burning oil in that engine depend upon the design of the engine and therefore are of interest to the engine designer who has to obtain certain results. On the other hand, each boiler plant is a problem in design in itself, and it is to help the designer of the oil-burning system that this Chapter is written.

A careful consideration of the principles involved in burning oil is becoming more and more necessary as the character of the fuel offered makes it more difficult to handle that fuel properly; for reasons given later, the fuel burned now is much heavier and more viscous than formerly and it frequently happens that equip-

*Chief Engineer, A. M. Lockett & Co., Ltd., New Orleans, La.

ment which worked well with light gravity oil is found totally unsuited for the heavier Mexican crudes or residuum.

The author has sub-divided this Chapter under headings which correspond with the order in which a prospective user of fuel oil would be most likely to consider the use of this fuel, as follows:

The supply of fuel oil.
Definition of fuel oil.
The advantages of oil as fuel.
The efficiency of oil fuel.
The purchase of fuel oil.
Oil storage tanks, their construction, and fire insurance rules covering same.
Unloading oil into storage.
Oil transfer, from tanks to burners.
The oil furnace.
Chimneys.
Marine oil burners
Operating accessories.

THE SUPPLY OF FUEL OIL

The advantages of any particular fuel, no matter how great, will not (unless in special cases, such as our Navy) interest particularly the steam plant owner unless the ultimate cost of making steam with that fuel is less than, or at least equal to, the fuel being used at the moment; nor would the business man want to spend money on equipment for burning a new fuel unless reasonably sure of a supply for a considerable period of time.

The annual production of crude petroleum in the United States is over 400,000,000 bbl., of which at least 220,000,000 bbl. (equal to 64,000,000,000 tons of coal) are burned as fuel; so that our domestic production of fuel oil is in itself a large item.*

But our near neighbor, Mexico, has practically unlimited resources in crude oil: oil is a cargo that can be easily and cheaply carried in ships; and as the freight on any fuel, whether coal or oil, is probably the largest part of its cost to the ultimate user, it is reasonable to expect that, as soon as ocean freight-carrying recovers from the disorganization incident to the war, and the fundamental cheapness of water transportation again becomes evident, all points easily accessible to our seaboard, from the

* Domestic production of crude petroleum amounted to 377,000,000 barrels in 1919; and 447,000,000 barrels in 1920.

Gulf Coast to New England, will be able to get fuel oil cheaply—in other words, oil will be the logical fuel all along our coast line. This statement refers to a large extent to oil from the Mexican fields, and does not relate to the field already supplied with fuel by our American fields, or rather refineries (as comparatively little crude oil is burned as such, the larger portion of liquid fuel being the residues from refining processes). The internal disorders in Mexico have, in addition to the diversion for war purposes, materially reduced the output of these fields, but oil producers look to much improvement in conditions there, which, with the cessation of the demand for war purposes, assure at an early date a large supply of this splendid fuel at a low price.

Our coast towns are already well supplied with distributing stations for oil. Peabody, as far back as 1915, compiled a partial list of these shore stations, which shows 73 such stations at Atlantic, Pacific and Gulf Coast ports, many of which can serve a considerable inland territory by inland waterway transportation; a list of these stations is given at the end of this Chapter. There is, of course, a very large territory already being served with oil fuel by rail transportation; the prospects of increased distribution by water transportation are mentioned to support the belief in a much wider use of fuel oil.*

DEFINITION OF FUEL OIL†

An explanation of the term "fuel oil" is appropriate here: probably the simplest definition is to say that "fuel oil" is any liquid fuel which commands a better price as fuel than it would if refined further into products such as gasoline, lubricating oil, etc. In the words of Dr. David T. Day, of the U. S. Bureau of Mines: "From the standpoint of the petroleum trade, fuel oil, in general, includes all oils which are not salable for some other special purpose at a higher price than that which prevails for oils to be sold as fuel oils or to be burned under boilers; from the trade point of view, it also includes special distillates which are sold as Diesel oils" (Diesel oils are ones used as fuel in oil engines).

* For a later discussion of fuel oil supply, see the paper on "Resumé of Fuel Oil Situation," presented to Forty-fourth Convention, Nat. Elec. Light Assoc.

† Methods of testing fuel oils and specifications for fuel oils are given on page 1235.

Hamor and Padgett* state that "the indefinite term fuel oil is employed broadly for the description of any product of petroleum which may be used for the production of heat or power, ranging from the distillate series down to and including any product which can be made liquid by steam heat and for which no better market outlet can be obtained. Generally speaking, there are no fixed specifications for fuel oil for industrial purposes, each user being guided by his own peculiar needs and facilities; it must not, however, contain naphtha, and many consumers require that it be of such a consistency that it can be pumped through pipes and burners."

During the early days of oil burning, the demand for the refined products, such as gasoline, kerosene, and lubricating oils, was more or less limited and consequently considerable oil was burned in the crude state. As the use and demand for the products increased, the crude oil became more valuable and the amount of residue (liquid fuel) available was greater, so more residue and less crude oil was burned, and the contrast became more and more marked as the demand for light distillate increased (due to the enormous expansion of the motor vehicle industry) and the methods of refining became more improved. The result is that very little American crude oil is burned now, and the fuel oil sold is a heavy viscous residue requiring special experience and special apparatus to burn successfully in a boiler furnace. Fortunately the Mexican crudes are physically very similar to our American residuums and the same methods of burning apply to each. It may be mentioned here that, heavy as are most of the Mexican crudes, and some Californian crudes, both have yielded to the refiner's skill, and are distilled for their volatile constituents; but the resultant residuum is a heavy mass that is a sore trial to the engineer who endeavors to burn it with the equipment which is used for lighter oils.

It is hardly necessary to state that by the term "crude oil" is meant petroleum in its natural state, as it comes from the well. Crude oil is a very complex chemical substance, composed of carbon and hydrogen (combined as hydrocarbons) with small percentages of oxygen and sulphur. The origin of crude oil has never been positively determined: it may be a product of vegetable, animal or mineral decomposition, or possibly a combination product; but the answer is of academic interest only,

*"The Examination of Petroleum," 158.

and the most interesting feature is the widespread distribution of oil over the globe, and the fact that new pools are constantly being discovered and developed in various parts of the earth, so that the supply seems likely to last longer than the more or less limited coal supply. There is a wide variation in the physical characteristics of crude oils.* There is presented on page 868 a table of a few of the more common crudes; in addition a table of several residuums is given (see page 875). There is, of course, a wide variation in the characteristics of residuum, too, but this is due principally to the stage at which the refining process has been stopped. It is interesting to note, however, that the difference in actual heating value in B.t.u. per gallon is much less, even for oils of widely varying specific gravities, than it is for coal from different coal mines.

A committee of the U. S. Bureau of Mines has recently published a *Bulletin* on the standardization of petroleum specifications, which gives five standard grades of fuel oils which, if adopted by the Navy and Shipping Board, will probably also come into general use by all users of fuel oil.

There is shown a series of curves which give several characteristics, such as specific gravities, flash-points and temperature-viscosity diagrams of some thirty different fuel oils. These curves are particularly interesting in that they give comparisons of the two most important physical characteristics of fuel oils,—namely, the specific gravity and the temperature-viscosity relation, of which further mention will be made later.

THE ADVANTAGES OF OIL AS FUEL

As mentioned before, the first consideration in selecting one of two or more available fuels, is, irrespective of their relative advantages, the net results in steam produced per dollar of fuel. This leads us to a comparison of the relative results from a ton of coal as compared with a barrel of oil.

Such a comparison involves two facts: first, the relation between the heat values, or the theoretical comparison; and second, the relation between actual evaporative results, or the practical comparison. The average heat value per pound of coal is probably not far from 13,000 B.t.u. per pound and for a pound of fuel oil it is about 19,000 B.t.u. per pound in round figures.

* On the chemistry and technology of petroleum, see BACON and HAMOR'S "American Petroleum Industry."

The evaporation per pound of coal will depend largely on the skill of the fireman, and whether hand-fired or stoker-fired; and while

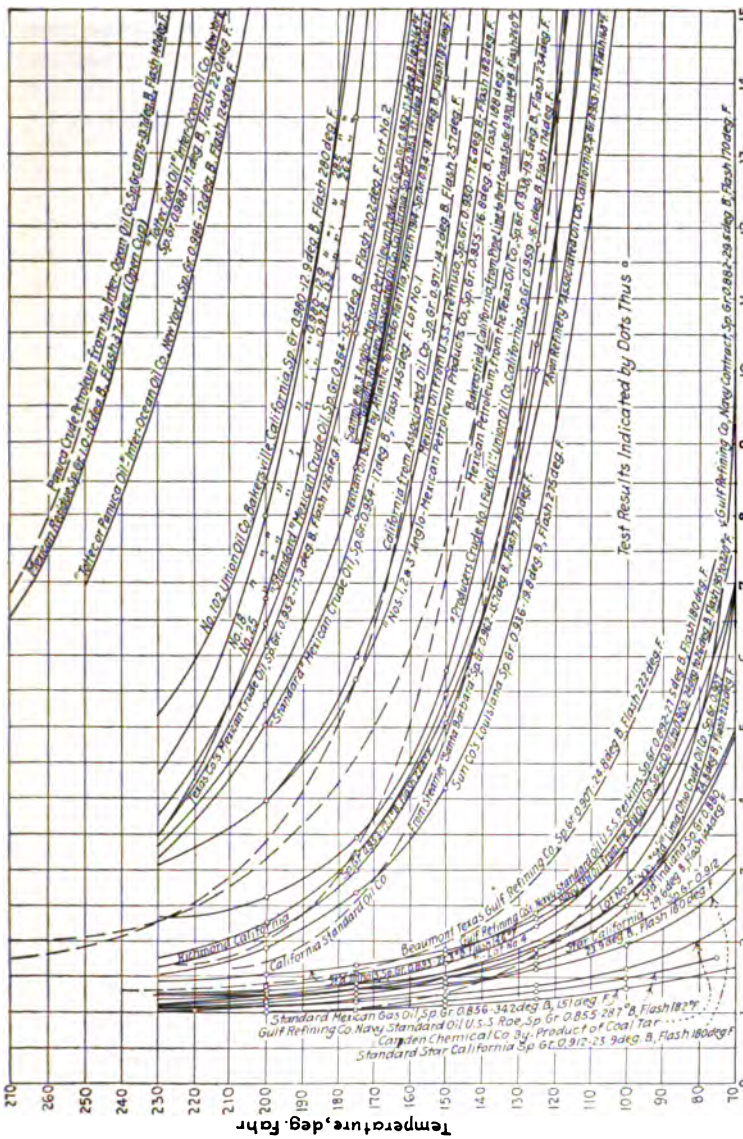


FIG. 196.

it may run as high as 10 lb. of water per pound of coal, from and at 212°F., it will probably in the majority of cases not average

over 8 lb. in boilers in regular service. With oil, whether in a large or a small plant, an evaporation of 14.5 lb. or more of water per pound of oil is readily obtainable with a fairly intelligent fireman, provided the oil-burning apparatus is of high class and the furnace properly designed. With this ratio as a basis, a pound of coal is equivalent to $8 \div 14.5$ or 0.541 lb. of oil. A barrel of oil weighing 325 lb. will therefore be equivalent to $\frac{325}{0.541}$ or 600 lb. of coal, and 3.34 bbl. of oil would equal one ton (2,000 lb.) of coal. A figure often used for rough comparison is that 3½ bbl. of oil equal a ton of coal. The following table shows the comparison in dollars and cents between various prices per ton of coal with the equivalent prices per barrel of oil, based on the above calculations. It must be remembered that this table is subject to variations, depending on the actual heat values of the oil and coal in question, and on the actual results being obtained from the coal.

There is also given a chart (Fig. 197), from which the comparison between coal and oil may be obtained graphically; this chart is based on the ratio of 4 bbl. of oil equal 1 ton (2,000 lb.) of coal, and is therefore more conservative.

Coal, price per ton (2,000 lb.)	Oil, price per barrel	
	See Note No. 1	See Note No. 2
5.00	1.50	1.66
4.75	1.43	1.60
4.50	1.35	1.50
4.25	1.28	1.42
4.00	2.10	1.33
3.75	1.09	1.25
3.50	0.53	1.02
3.25	8	1.01
3.00	0.98	1.00
2.75	0.80	0.92
2.50	0.73	0.83
2.25	0.65	0.75
2.00	0.60	0.66

NOTE 1.—Oil, price per barrel, not allowing for labor saving.

NOTE 2.—Assuming 10 per cent of cost of fuel in labor of firing and handling ashes saved by using oil—a conservative estimate on plants of over 300 hp.

Another easy rule of comparison of prices is given by E. H. Peabody in his "Oil Fuel," p. 19, as follows: "Thus, approximately, when the cost of coal in dollars per ton (of 2,240 lb.) is double the cost of oil in cents per gallon, the fuel costs of producing steam will be equal." This comparison, however, is more applicable to marine practice because it is based on high-grade steamship coal of 14,400 B.t.u. and low-grade fuel oil of 18,600 B.t.u. For stationary practice, the table and chart given above are more suitable.

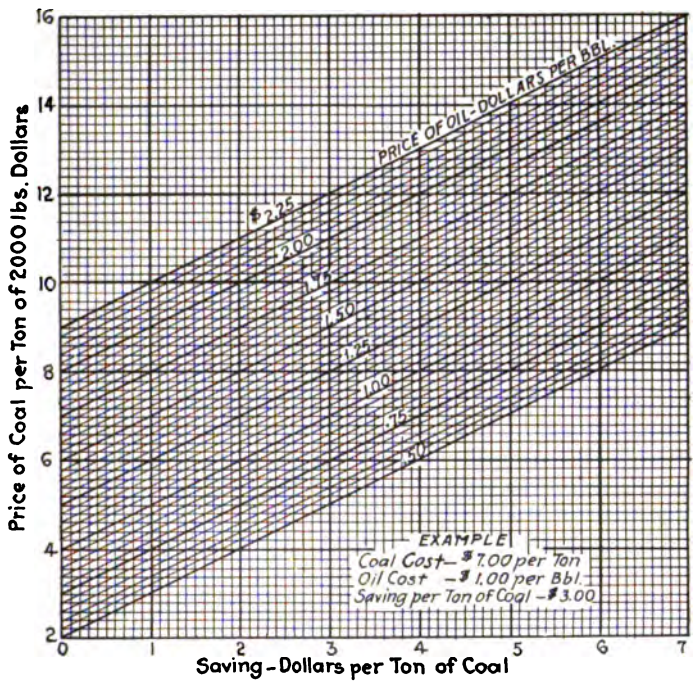


FIG. 197.—Chart showing comparison of oil and coal.

If the above figures show that the price of fuel oil for any particular plant compares favorably with coal, the many advantages of oil fuel will warrant its use. These advantages, for marine boilers, are so marked that other considerations than actual price comparison with coal will frequently make the use of oil fuel desirable, even at a much higher price than coal; in fact, the question of adequate supply stations should really decide whether a ship will use oil or coal. Some of the advantages, both for marine and stationary work, are well expressed in the following extract from *Bulletin* 32 of the California State Mining Bureau:

"**Transportation.**—The first advantage is ease of transportation. This may not amount to much to those who have their fuel delivered at their doors, but in situations where fuel must be transported as used, notably on steamships, it is a very important matter. The loading of a steamship with coal requires days where an equivalent quantity of oil may be loaded in as many hours, and entirely without labor. By modern devices oil may be pumped into or out of vessels at points where it would be impossible to dock and discharge or take on a cargo of coal, while vessels at sea may transfer supplies of oil in weather which would quite prevent transferring of coal. The fuel tanks of oil-burning locomotives are loaded with the turn of a valve, and in a minimum of time, while tank wagons deliver oil to stationary plants where the handling of coal would create a nuisance, from the dust raised, as well as seriously depreciate the value of the solid fuel.

"**Storage Space.**—Where a supply of fuel must be stored, a second advantage in the use of liquid is shown. If we assume as a basis that 4 bbl. of oil are equal in fuel value to 1 ton (2,240 lb.) of good bituminous coal, the oil occupies a space less than three-fourths as great as would be required for the coal; to be more accurate, the 4 bbl. of oil would occupy a space of 22.5 cu. ft., the ton of coal from 32 to 38 cu. ft., making the space required for the oil from 59 to 70 per cent of that taken by the coal. Furthermore, no matter how limited boiler room space may be (and in office buildings, etc., this space often represents considerable value), the working supply of coal must always be on the boiler-room floor, while the oil supply may be, and in such cases generally is, buried under the sidewalk or the cellar floor, thus taking no space whatever which would be of any value for other purposes, beyond that required for the manhole and the connections.

"**Cleanliness.**—The cleanliness incident to handling and using oil is too manifest to need argument. The coals obtainable on the Pacific Coast, at least, produce great quantities of dust, soot, and ashes. With any proper care in the handling of oil, all these disadvantages may be done away with, and the boiler room kept as clean as a well-regulated engine room. In many lines of business, this is a very important matter to the user of fuel, and where oil is in general use, as it is in San Francisco, the alteration in the appearance of the city, due to the removal of the smoke from coal fires, is very great.

"**Labor.**—The labor of handling, and most of the labor of stoking, are done away with, although the oil fires naturally require some attention. The greatest saving of labor, after that of firing, is in the cleaning of fires and flues. Oil fuel does away, of course, with clinkers, and therefore with the very trying labor of slicing and cleaning fires, while, if properly regulated, the boiler flues may be kept much cleaner. The latter not only reduces the labor of keeping the flues clean, but also considerably reduces the waste of fuel through imperfect transference of

heat through the tubes to the boiler water. The removal of the necessity of constantly opening and shutting firedoors reduces strains on both brickwork and boilers, prolonging the life of both, though this advantage may readily be lost by carelessness in handling an oil fire, due to the greater ease with which the latter may be forced.

"**Regulation.**—The ease of regulation is a great factor in the economy realized in the use of oil fuel. The fire may be kept at a constant point for hours at a time, or may by the turn of a valve be made to respond to the most unusual demands for power. Where the call for steam is fluctuating, as on locomotives, where the demand for power may fall within a few seconds from the maximum capacity of the apparatus to absolute zero, this is of great importance. By the simplest contrivances

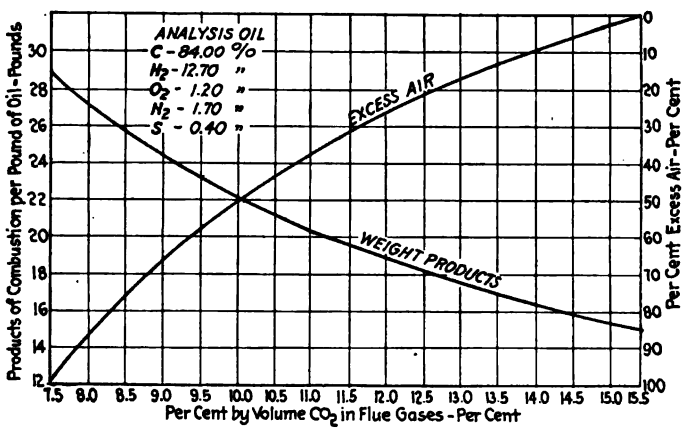


FIG. 198.—Curve showing relation between carbon dioxide and excess air for oil fuel.

and the most ordinary attention, the needle of the steam gage on a heavy freight locomotive may be kept almost stationary up hill and down, and through stops of any length. This ease of regulation is perhaps most appreciated where temperature is a factor, as in running or in heating metals. Temperature of an oil still may be regulated to a nicety and with the greatest ease, while every one called on to heat iron or steel will appreciate the ease with which the right temperature for forging or other operations is reached and maintained.

"**Capacity.**—The increase in steaming capacity of boilers is considerable. There is some disagreement as to figures, but it would certainly be conservative to claim that, with a proper oil installation, a boiler may be made to deliver from 30 to 50 per cent* more steam than could possibly be gotten from it with coal, without the use of forced draft."

* Since this was written, improvements in furnaces and burners make possible much higher capacities than these. See curves showing tests of steam atomizing and mechanical atomizing furnaces (Fig. 259).

THE EFFICIENCY OF OIL FUEL

One of the fundamental reasons why liquid fuel is desirable is the fact that efficient combustion is possible and not difficult of attainment. The source of heat in all commercial fuels is the rise in temperature that takes place when the constituents, principally carbon and hydrogen, unite chemically with the oxygen of the air to form oxides. If more air is admitted to the burning fuel than is necessary to furnish the oxygen required for perfect combustion, the surplus air abstracts useful heat from the furnace and wastes it up the stack. With ordinary coal fires, it is impossible, with present boiler furnaces, to reduce the amount of air to within a considerable percentage of the theoretical minimum without causing incomplete combustion, which is even more wasteful than excess air, since the product of the partial combustion of carbon, carbon monoxide, is a combustible gas in itself and retains a considerable percentage of the total available heat in the coal.

In the case of an oil flame, the fact that the fuel, under proper conditions, is broken up by the burner, or atomizer, into a great number of very small particles, each of which exposes a large surface in proportion to its volume to the oxygen of the air, makes it possible to reduce, to very near the theoretical minimum, the amount of air necessary for complete combustion. In addition to the facility afforded the actual combustion of the fuel particles, is the further fact that the shape of the flame can, by proper arrangement of furnace and selection of type of burner, be so proportioned that the air enters only where it is needed for combustion.

The surest index to combustion is the proportion of carbon dioxide (CO_2) in the flue gases. There is about 21 per cent of oxygen by volume in air; so that if the combustible matter in a fuel were all carbon, perfect combustion would be indicated by 21 per cent CO_2; but in coal and oil there is a considerable percentage of hydrogen, which unites with oxygen in the furnace to form H_2O, or water, and which is not indicated by the flue gas analysis. Therefore the greatest percentage of CO_2 possible in flue gas is not 21 per cent. but less by the amount of hydrogen in the fuel. For fuel oil, this theoretical maximum is from 15 to 16 per cent of CO_2; therefore, when a gas analysis indicates 14.5 per cent of CO_2, it is evident that very nearly perfect combustion has been attained.

It is interesting to note that the perfect efficiency of a boiler furnace is not 100 per cent, but is less, due to unavoidable losses of heat in the flue gases. For the minimum excess air supply, which is about 10 per cent, and allowing 3 per cent for brickwork radiation, the ideal efficiency of furnace and boiler is about 84.2 per cent; so that, when actual tests show boiler efficiencies of 80 per cent or more, it is also evident that almost perfect results are obtainable with oil fuel.*

In the great majority of coal furnaces, particularly hand-fired, the CO_2 is probably not over 9 per cent, though in stoker-fired boilers probably 11 per cent is attained on the average. In properly designed and operated oil furnaces, the CO_2 will often go as high as 14 or 15 per cent, even in small installations. In terms of boiler efficiency, the average combined furnace and boiler efficiency of well-kept coal-fired boilers is about 65 per cent, and for the same boiler with an oil furnace it would be about 75 per cent. There are, of course, exceptional cases of both coal- and oil-fired boilers where the above figures are exceeded.

The figure of 75 per cent efficiency for oil is the actual ratio of B.t.u. input to useful heat (or steam) output; the theoretical efficiency of actual combustion is greater, for the following reason, which is not often realized and which explains an inherent loss in burning oil: the point that is seldom brought out in relation to the heat value of oil is that the heat units per pound as usually given are higher than the heat usefully available when that oil is burned in a boiler furnace; the reason is that oil contains a considerable proportion of hydrogen (about 12 per cent), and this hydrogen, in burning in a furnace, combines with oxygen to form water in the form of steam, the latent heat of evaporation of which is lost up the stack. This loss amounts to approximately 7 per cent, varying with the percentage of hydrogen and the total heat in the oil. This item is of academic interest only, as there is no way of recovering the latent heat of the steam lost up the stack, and is mentioned to show why actual efficiency with oil is not entirely perfect, as one would expect from the possibilities for perfect combustion explained.

Unfortunately, the same ease with which the excess air supply to an oil furnace may be reduced to a minimum, makes it possible to admit even more excess air than with coal; this may be due either to improper oil burners and furnace, or to ignor-

* See C. R. WEYMOUTH'S "Unnecessary Losses in Firing Fuel Oil."

ance or indifference on the part of the fireman. While the use of oil fuel greatly reduces the quantity of labor for firing, it also makes necessary, for efficient results, the employment of more intelligent and conscientious firemen. A careless or ignorant operator can easily waste in fuel several times the salary of a competent man, using the same apparatus.

THE PURCHASE OF FUEL OIL

Oil is sold in units of volume rather than weight, the unit being the barrel of 42 U. S. gal. As the volume of a given weight

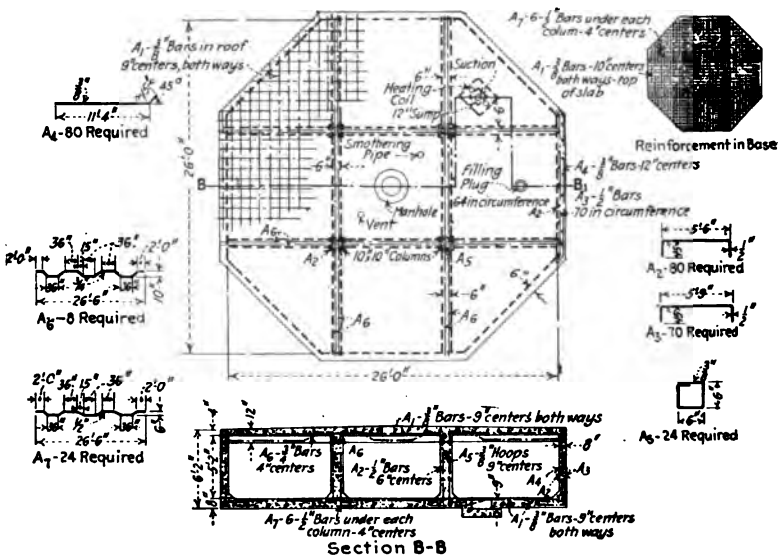


FIG. 199.—Concrete oil-storage tank.

of oil varies considerably with the temperature, this volume must be based on a definite temperature, which is usually 60°F. This is an important point to remember, particularly when checking quantity by gaging the tanks, for the temperature at which oil, particularly the heavier grades, is handled may easily cause an error of 5 per cent or more, generally making the quantity appear greater than the true figure. A much more logical way to sell oil would be by weight, using the ton as a unit.

The purchaser of fuel oil should, in comparing different oils, compare their heat values, just as in purchasing coal. The fact that one oil may be heavier and therefore more viscous than

another should really make little difference (popular belief to the contrary notwithstanding) in considering its value as liquid fuel, since, by proper preparation for its use, just as good results can be obtained from the heavier fuel; in fact, there is one distinct advantage in that the heavier the oil, the more apt it is to be a residuum with its lighter constituents "topped" or distilled off, making its flash-point high and considerably reducing the danger from fire. An oil with a flash-point lower than 150°F. is rather dangerous as a fuel and its use as such is likely to raise objections from the fire insurance authorities.

Oil being sold by volume, and its quality usually specified in degrees Baumé (a scale indicating gravity) and heat units per pound, it is necessary in comparing heat value per dollar to reduce each fuel to the same terms; a convenient method is to calculate the weight per barrel with the aid of the table given for converting degrees Baumé to pounds per gallon, which weight multiplied by the B.t.u. per pound gives the heat units per barrel.

Where the heat units per pound are not known, the value may be estimated approximately (after measuring the gravity in degrees Baumé by a hydrometer) by means of an empirical formula which, it is claimed, gives results approaching the average chemical analysis. This equation was published in the October, 1908, number of the *Journal of the American Chemical Society*, and is as follows: Calorific value in B.t.u. = 18,650 + 40 (Baumé reading − 10).

It is claimed that, on comparing the actual heat value from a test in a calorimeter, with the calculated value using the above equation, in the 64 samples tested, in only one-thirtieth of the cases was the variation greater than 2 per cent.

It will be noticed that, wherever the characteristics of an oil are given, the weight is usually expressed in degrees Baumé, the Baumé scale being adopted for this purpose. There are two Baumé scales, one for liquids heavier and one for liquids lighter than water; the number representing 1.00 sp. gr. is 10° on both scales, so that an oil, for example, of 11° Baumé may be either lighter or heavier than water. As long as all fuel oil handled was lighter than water, no confusion resulted; but with the use of Mexican crudes and heavy residuum it is quite common to have oil of 10 or 11° Baumé (lighter than water scale), and undoubtedly heavier oils will be on the market soon. The opinion of the author is that oil should be sold in terms of actual specific gravity,

which, in any case, would facilitate calculation, without the necessity of referring to tables or converting degrees Baumé to specific gravity.

THE OIL-BURNING INSTALLATION

Three separate problems must be considered in a stationary-boiler plant installation (the marine installation is a separate case and will be mentioned later). The first is the oil-storage system; the second, the transfer of the oil from the storage tanks to the oil burners under the boilers; and the third, the burners and oil furnaces under the boilers.

OIL STORAGE

The question of storage facilities for fuel oil is one which, to a large extent, must be decided in each particular case according to the local conditions. Where a plant is located near a supply station with proper delivery facilities, a small storage tank will be sufficient, though, as oil is usually purchased in car lots, the tank should hold at least a carload, which varies from 7,000 to 12,800 gal. per car. Or, again, where deliveries are more uncertain, it may be necessary to store more oil, and larger tanks will be required; in such cases, it is customary to use a small auxiliary tank near the boiler room, with a larger supply tank at a convenient location. If the plant is in a city, insurance requirements may largely govern the size and location of the tanks. It is advisable, before deciding on storage arrangements, for oil users to consult the local Fire Underwriters for advice.

A very common arrangement in many plants is the use of an underground tank near the boiler room as a service tank, with a larger above-ground storage tank as the supply tank. In cities, it is the general practice to use only the underground tank, which is buried near the boiler room, and filled from tank wagons, or, if accessible to a switch track, filled direct from the tank cars. The size of the storage system and the question of arrangement are rather matters of judgment than of an engineering nature.

The size and arrangement of tanks being decided upon, the materials of which the tanks will be built must be determined. Practically all tanks used are of riveted steel construction, but the author believes that, in time, the merits of concrete storage tanks will be realized, and the present doubt or prejudice against their use cleared away. There seems to be a belief that

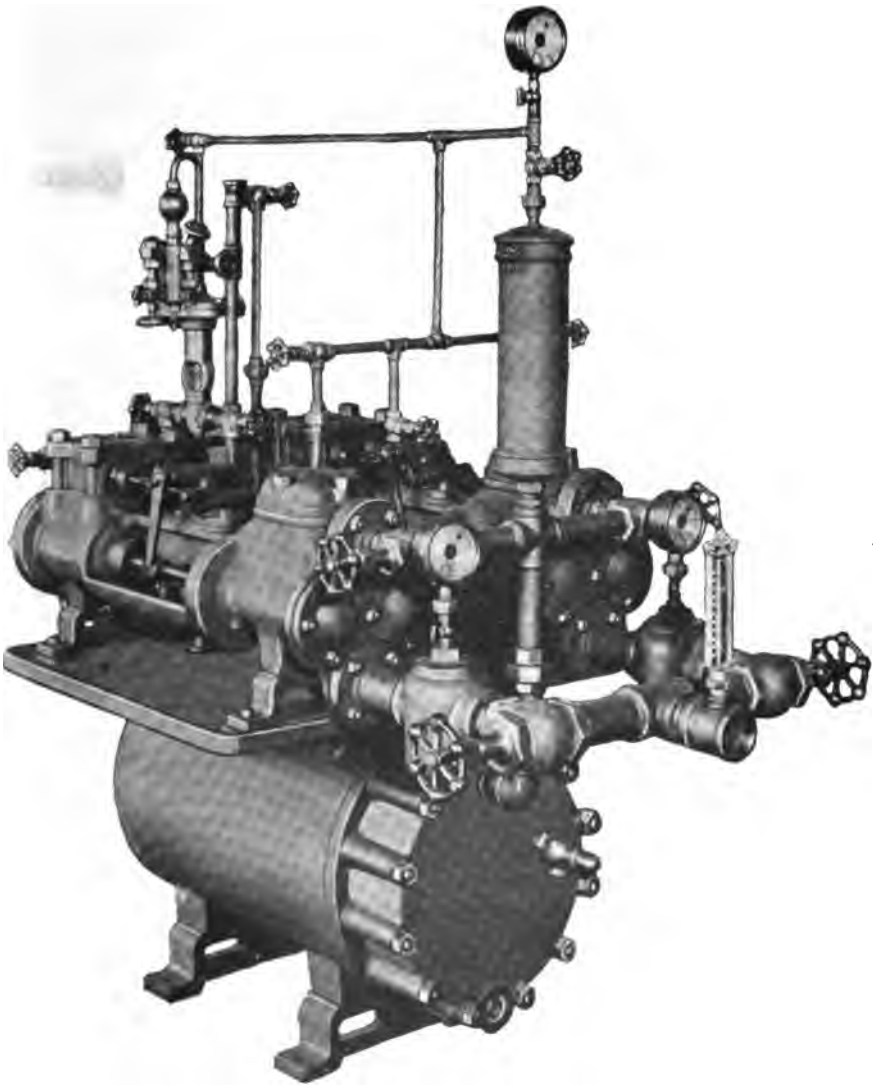


FIG. 200.—An oil pumping set, size 4½ × 2¾ × 4, manufactured by A. M. Lockett & Co., New Orleans, La.

fuel oil affects concrete, but this the author believes to be erroneous, as tests have been made by mixing oil with concrete to waterproof it, with apparently no effect on its strength. The author knows of several concrete tanks for oil which have been in use for several years.* The thickness of steel required for steel-riveted tanks of various sizes, as well as rules for the location and installation of these tanks, is well standardized in the rules and requirements of the National Board of Fire Underwriters.

UNLOADING OIL

The following data as to unloading oil to tanks and measuring it, are pertinent here.

Fuel oil may be delivered to any given plant by tank car, by boat, or by pipe-line; tank cars have a capacity of from 7,000 gal. to 12,800 gal. per car. Tank cars are equipped with 4-in. discharge pipes looking downward near the center of the car, the end of the pipe being controlled with an internal valve operated with a stem from the top of the car.

Where conditions permit oil to be discharged from tank cars by gravity, the best arrangement is to place a 10-in. pipe in the ground, between the rails, with 10-in. openings, 43 ft. center to center, corresponding to the length of the longest tank car. These openings will be 10-in. nipples, threaded to receive pipe caps when they are not in use. Several cars of a train can in this way be discharged at one time, the 10-in. pipe being large enough to receive the oil from the 4-in. discharge pipes of the car when the valve of the car is wide open, and in this way, with the oil in the tank car heated as may be necessary, a tank car can be discharged in 30 min.

Ordinarily no strainer is employed in taking oil from tank cars in this way.

Usually the one 10-in. pipe will have a branch to each of two oil storage tanks, with a gate valve at the entrance of each tank.

Some insurance rules recommend that the entrance pipe to the tank extend to near the bottom of the tank, so that its end will ordinarily be sealed with oil, thus preventing the possibility of the

* Since this chapter was written, there has developed a considerable use of concrete tanks, due to the scarcity and high price of steel which make the cost of concrete tanks compare favorably with steel; a design typical of several installed by the author is given here; there is also presented a typical insurance specification of concrete oil tanks.

ignition of any gas within the tank by means of flame carried through this pipe.

Oil frequently is received from tank cars by means of flexible hose, which is connected to the 4-in. discharge pipe at the bottom of the tank.

Flexible connection often is made by means of a length of pipe about 6 ft. long, with two elbows and two nipples at its end, two elbows and a short vertical nipple connecting it with a second piece of pipe of about the same length, which is connected by a fifth elbow and short vertical nipple with a pipe line buried in the ground at one side of the track, all so that the turning of the nipples within the elbows on the pipe thread enables the end of the pipe to be swung under the tank car and connection to the tank car to be made by means of a ground union.

To empty a tank car by means of a 3-in. pipe or flexible hose, as described, requires about three hours under the same conditions that would require thirty minutes with the 10-in. pipe.

It sometimes has happened that the oil valve in the car for controlling the discharge of oil has been out of order, and that, due to the connection between the car and the discharge pipe not being secure, a large part of the oil within the tank car has been lost. Therefore, this connection should be capable of withstanding a pressure of a 10 ft. head of oil or the receiving pipe should be large enough to carry the oil away without any connection between the pipe and the car whatever.

Of course, where storage tanks are above the level of the rails, it is necessary to pump oil from tank cars into the storage tanks. This is ordinarily done with the 4-in. pipe connection having flexible joints, as described above, from the bottom of the car, and it is sometimes done by dropping a pipe with a flexible hose connection into the car through the manhole above.

When oil is received by steamer, it is, of course, pumped into the storage tanks.

The usual method of reading the quantity of oil received is by means of gaging the receiving tank; that is, a rod of iron or wood, with divisions marked on it, is inserted from above and extends down to the bottom of the tank, and, when it is withdrawn, the height of the oil within the tank is plainly visible on the rod. Reference to a table then determines the amount of oil within the tank before and after receiving the additional supply. Con-

siderations of accuracy in gaging tanks in this way make it advisable to have at least two tanks in any one plant.

It frequently happens that a wooden float is placed within the tank and connected by a chain extending up over a pulley to a counterweight which slides on a graduated slide, enabling gallons to be read directly from the tank. This arrangement is objectionable in that insurance regulations recommend that there be no openings into tanks except a vent pipe which must be protected by a fire trap, which is a screen of perforated metal or fine wire gauze placed between flanges in the vent pipe to prevent the possibility of a flame passing down the pipe and igniting the gas within the tank.

When a float indicator has been used as described above, it has been customary to pass the chain up through the vent pipe of the tank, which, of course, prevents the presence of the fire trap which should be used. The tank, therefore, must be gaged with the rod as described, or by such an indicating gage as may be devised which will not necessitate direct connection with the outer air.*

OIL TRANSFER

The above paragraphs cover the taking of the oil from the tanks and delivery to the burners; it is assumed that all systems of any importance will involve the mechanical delivery, by pumps, to the burners, as gravity feed to the burners is not permissible under insurance rules. It is further assumed that a new system will be fitted for the use of heavy fuel, comparatively little light oil being burned under boilers for reasons already explained.

It is an axiom that heavy oil must be heated each time it is moved. Consequently the storage tanks should be fitted with steam heating coils. The amount of coils necessary in any given tank varies with the climate, so no rule can be given; this applies principally to above ground tanks. For buried tanks of carload capacity, a live-steam coil of 30 or 40 ft. of ¾-in. pipe is usually sufficient. A common mistake is to heat oil in the storage tank too hot; this is wrong for several reasons: it wastes steam unnecessarily; it may cause the pumps to become gas-bound if drawn by suction from the tank; and if there is some water mixed with the oil, as is often the case, it may produce

* The above data on unloading oil are published through the courtesy of the Babcock & Wilcox Co.

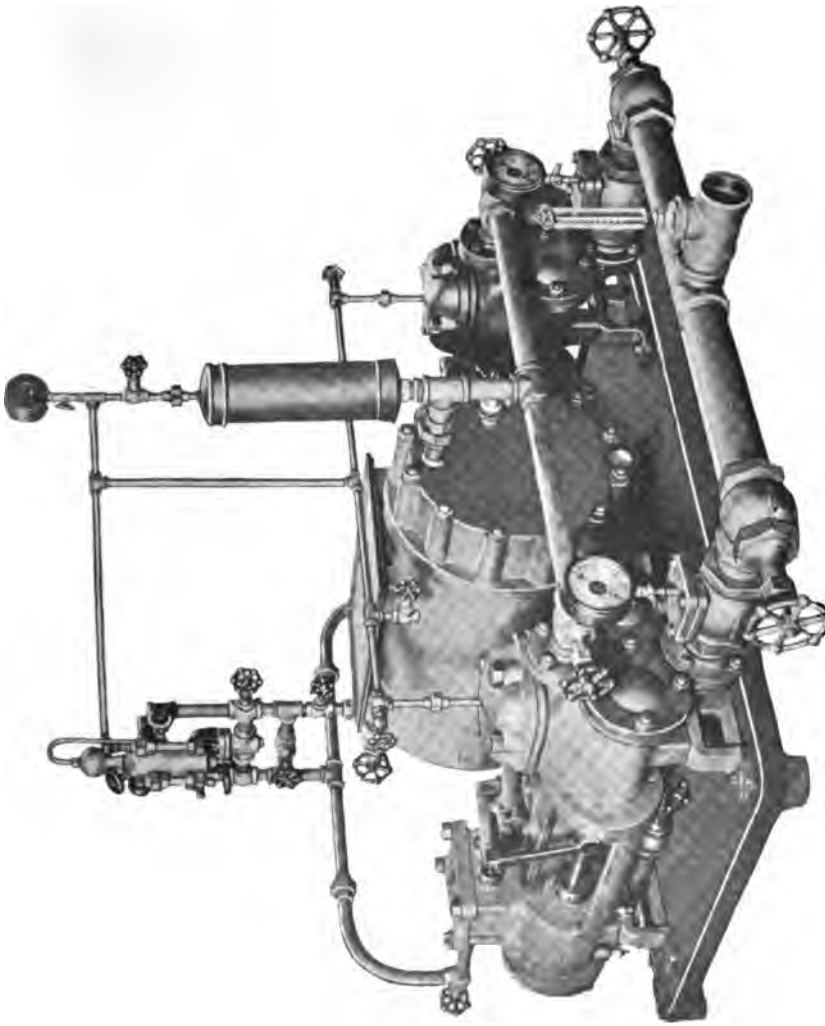


FIG. 201.—An oil pumping set, size 5½ × 3½ × 5, manufactured by A. M. Lockett & Company, New Orleans, La.

steam bubbles in the oil, which will cause the tank to foam over with dangerous results.

The proper temperature in the tanks varies somewhat with the particular fuel, but generally about 100 to 150°F. in a suction tank will enable the pump to draw the oil properly. In planning steam connections to oil tanks, provision should be made for a steam line to the tank car; a ¾- or 1-in. pipe connection is usual.

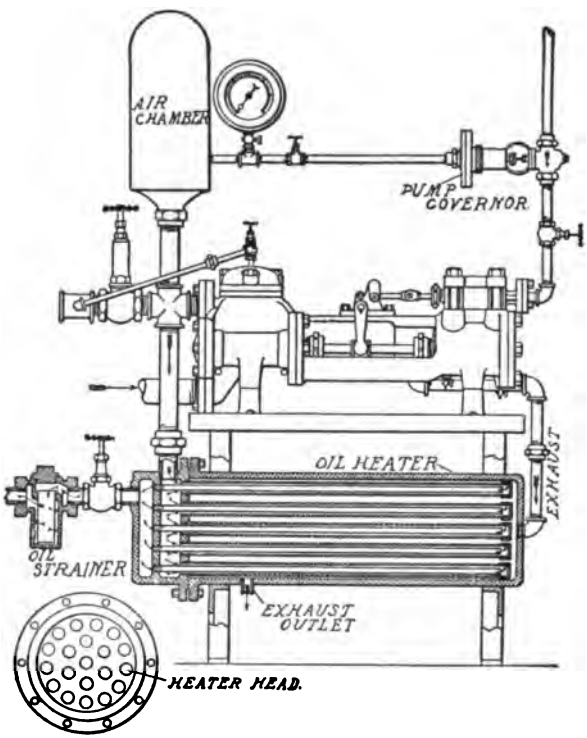


FIG. 202.—Oil pumping set, G. E. Witt Company.

Where a large main storage tank is used in connection with a small underground service tank, it usually will be found necessary to not only heat the oil in the main tank but to furnish a pump to deliver the oil to the service tank. The pump ordinarily used for handling oil for this service, as well as for delivering the oil from the service tank to the burners, is the duplex piston pattern type of pump, such as the Worthington or Blake. Such a pump, when fitted with brass or babbitt ring packing in the oil piston, and

oil-proof gaskets and gland packing, and with cylinders corresponding to boiler-feed pump sizes, works very well even though handling heavy oil. It is necessary to reduce the piston speed in order to reduce the velocity through the valves to 100 ft. per minute or less; a safe rule is to figure the pump to run at not over 25 or 30 single strokes per minute up to pumps of 12-in. stroke. The table given on page 828 shows the rating of pumps for feeding oil to boilers used by a well-known manufacturer.



FIG. 203.—The Coen oil-pumping set.

OIL FEED TO BURNERS

The proper feeding of oil to the burners from the service tanks involves several distinct requisites, viz.: straining the oil to keep dirt out of the pumps and burners, heating the oil to a rather high temperature, maintaining a uniform oil pressure, and providing safety devices to guard against dangerous pressure on the pipe system. While a skilled engineer probably can select the various pieces of apparatus to perform these various functions, it is safer to purchase what is called an automatic oil pumping set, of which

there are a number on the market. Illustrations are shown of several well-known types which vary principally in details of construction. The several essential features embodied are as follows: two pumps, either of which will carry the load, reserving the other as a spare; suction strainers on the pumps; pressure governor, air chamber, heater, oil and steam relief valves, thermometer, and gages.

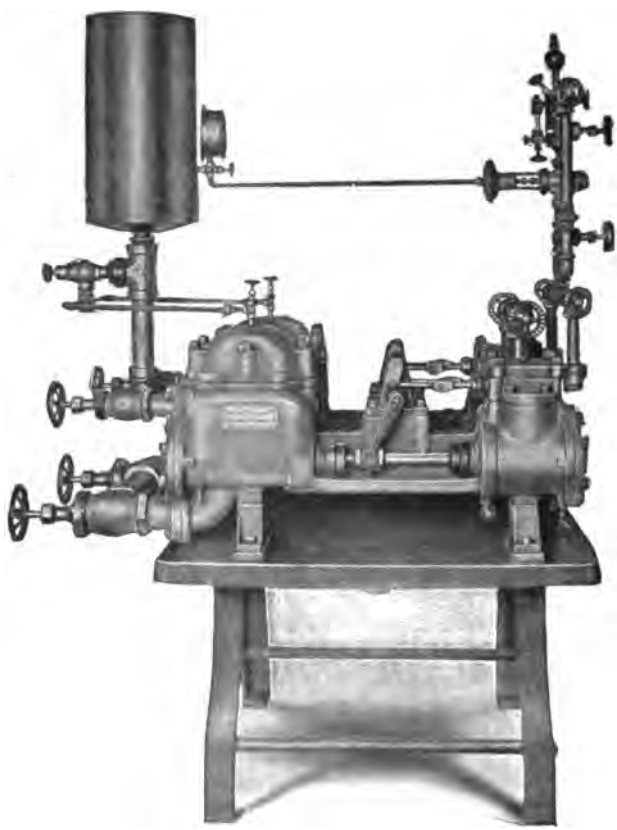


FIG. 204.—An oil-pumping set manufactured by The Coen Company, Inc., 112 Market St., San Francisco, Cal.

For heavy fuel, the heater is a vital part of the system; the temperature to which the oil should be heated depends on the viscosity of the oil, because the heavier the oil the higher the temperature. In general, it may be said that fuel oil, in order to enable the burner to atomize properly, should have its viscosity

reduced to about 8° Engler, as determined by a viscosimeter. This determination is usually the result of experiment in the boiler furnace rather than by viscosimetric test; but the heater should be capable of heating the oil to at least 200 or 225°F.

Heaters are of various types: some have steam coils in a vessel through which the oil passes; others reverse this and pass the oil

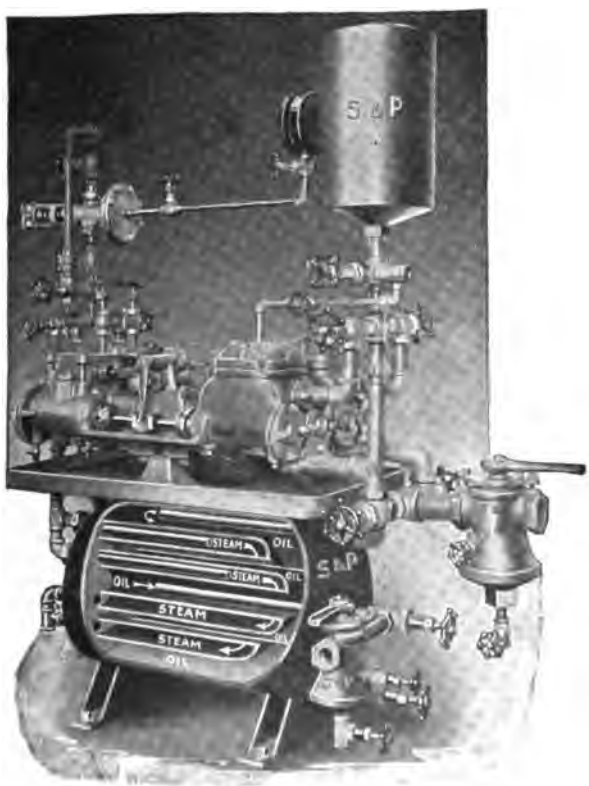


FIG. 205.—The Staples & Pfeiffer self-contained, self-cleaning, self-governing, automatic oil-pumping, heating and filtering system.

through the coil; while several use straight tubes of the so-called porcupine type, where each tube has an inner tube through which the oil passes in and out again around the outside between the inner and outer tubes. The writer believes the porcupine type most effective, and Figs. 209 and 210 show a heater of this type, where the velocity through the tube is doubled by a two-pass effect, making a highly effective heating surface.

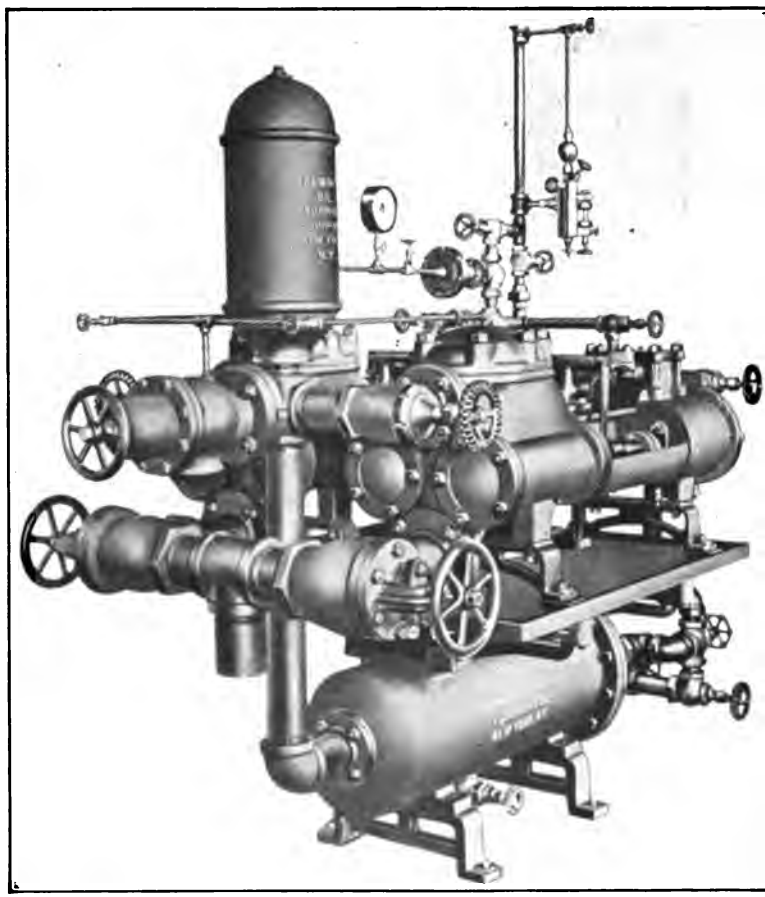


FIG. 206.—The duplicate oil-pumping set, single heater type, manufactured by the Hammel Oil Burning Equipment Company, New York, N. Y.

PIPING SYSTEM

The design of the oil-piping system between the tank and pumps and between the pumps and burners calls for especial care with heavy fuel. It is well to put the pumps as close to the tank and as close to the floor as possible, to reduce the friction and suction lifts. Where the suction is long, it should

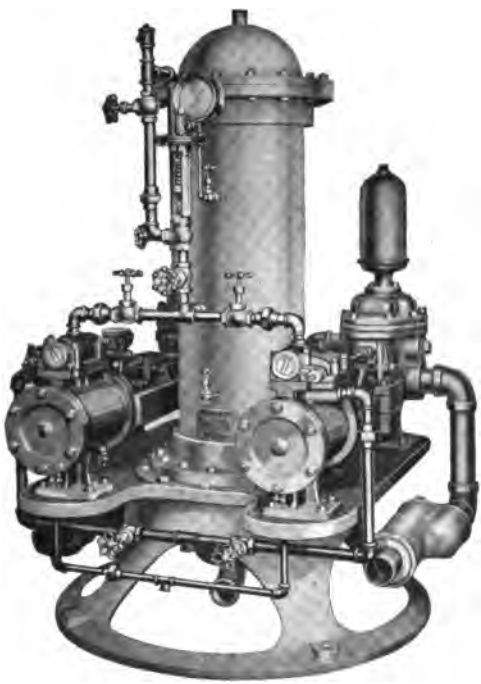


FIG. 207.—An oil-pumping set manufactured by Tate, Jones & Company, Pittsburgh, Pa.

be one or two pipe sizes larger than the pump suction; it is always desirable to use easy sweep bends in the suction rather than elbows. The pipe should slope upwards about 1 in. in every 10 ft. toward the pump; a foot valve on the tank end of the suction is not desirable, but, where necessary, should have a metal-to-metal seat, as leather or rubber is affected by oil. Suction pipes should be laid either in dry ground or in a well-drained wood or concrete trench; in cold climates it is desirable to insulate with pipe covering.

The discharge pipe from the pumps to the burners should be large, a velocity of 100 ft. per minute being considered good



FIG. 208.—A fuel oil-pumping outfit manufactured by the Worthington Pump and Machine Company, of New York, N. Y.

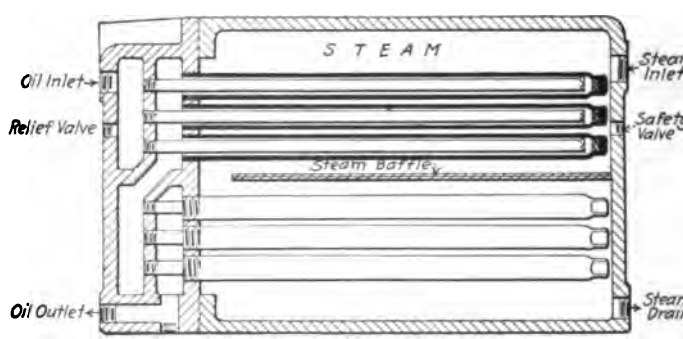


FIG. 209.—Sectional view of A. M. Lockett & Company, Ltd., Nelson multi-pass film type porcupine oil heater.



FIG. 210.— The Nelson vertical oil heater, porcupine two-pass type, 6000 horse-power size; this heater is manufactured by A. M. Lockett & Company, New Orleans, La.

practice. It is very desirable that the discharge line be well insulated, particularly if long; it is quite common to supplement the oil heater by running a small live steam line inside of the oil header, with a stuffing box at one end to provide for expansion. This steam pipe makes possible the heating of the oil in the discharge line when starting up a cold installation; this is necessary because heavy oil, with its high flash-point, will not ignite at ordinary temperatures, but must be heated first.

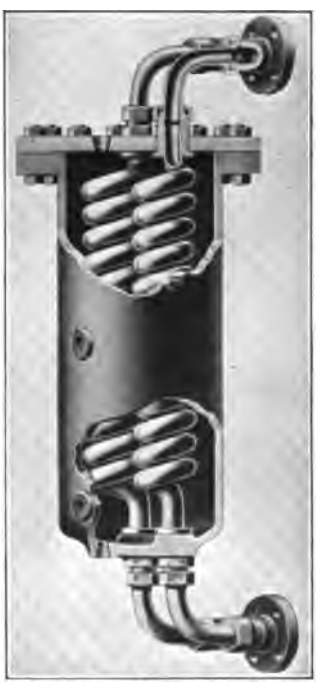


FIG. 211.—The Reilly oil heater.



FIG. 212.—The G-R oil heater.

It is also customary to run a circulating line from the farthest end of the oil header back to the suction tank; this makes it possible to circulate oil through the system preparatory to starting up, a great convenience with heavy fuel. Standard weight pipes and fittings are satisfactory for oil lines to burners, though it is preferable to use valves, at least, of high grade 175-lb. pressure type, as they are much less apt to leak than cheaper valves. Some engineers prefer to use extra heavy fittings as well, since they enable the threaded joints to be



FIG. 213.—The film oil heater manufactured by the Schutte & Koerting Company, Philadelphia, Pa.

screwed up tighter without stretching or cracking the fittings. All oil joints should be made up with some compound not affected by oil. The substance generally used is a mixture of



FIG. 214.



FIG. 215.

FIG. 214.—The oil heater manufactured by The Coen Company, Inc., San Francisco, Cal. The Coen Company, Inc., has discontinued the manufacture of the multi-unit, land-type oil heater, owing to the fact that this appliance was quite bulky and difficulty was experienced in cleaning it. The Company has put on the market a new heater, that shown above, which is readily cleanable and which does not make use of coils or tubes. This heater will be used for either stationary or marine work.

FIG. 215.—The oil heater of The Coen Company, Inc. *A* is the oil inlet; *B*, the condensate outlet; *C*, the steam inlet; and *D*, the oil outlet. The fuel oil is heated in a spiral oil flame, by causing it to flow over a surface which is heated internally by means of steam; the oil flows out at a high velocity in order to obtain maximum heat transfer.

litharge and glycerine; but to secure results with this composition, it must be mixed in very small quantities, and applied im-

mediately, as it sets in a few minutes very much like cement,



FIG. 216.—The Coen air register, which is built in 2 sizes, 18 in. and 22 in., respectively, for marine and land boiler installations. This register is designed to give an intimate mixture of the air supply and spray with a minimum of draft restriction.

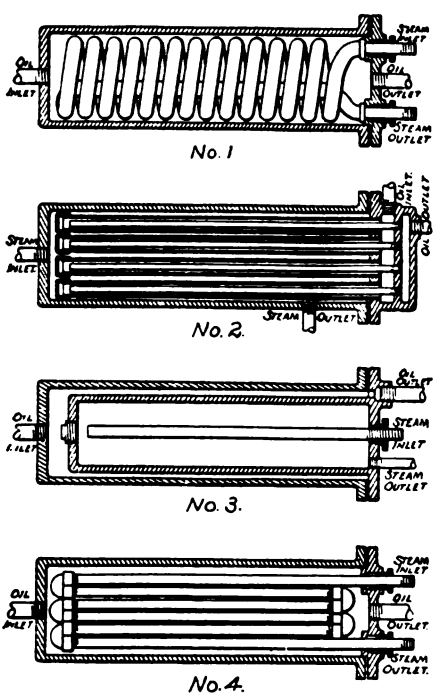


FIG. 217.—Types of oil heaters, G. E. Witt Company.

but more quickly, and does very little good if the thread is screwed after the composition has hardened.

Two thermometers are essential on an oil burning installation: one should be located in the burner-supply pump suction, as a

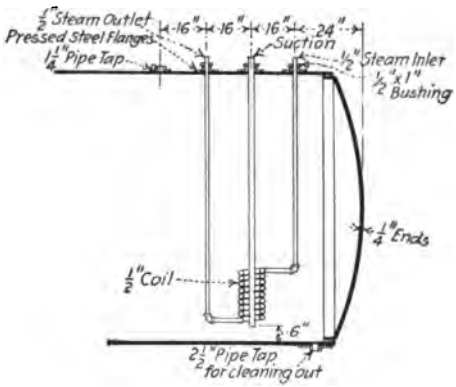


FIG. 218.—Sketch of oil tank heating coil, Tate-Jones Company.

guide to the temperature of the oil in the suction tank; the other should be in the oil discharge line, to indicate the temperature of the oil at the burners. Some judgment must be



FIG. 219.—The Coen duplex oil strainer. *A* and *B* show the two parts of the strainer basket; the combined area of the perforation of the total baskets is from 6 to 10 times the cross-sectional area of the pipe.

used in locating these thermometers, so that their stems will be in the oil current; the author has seen several cases where

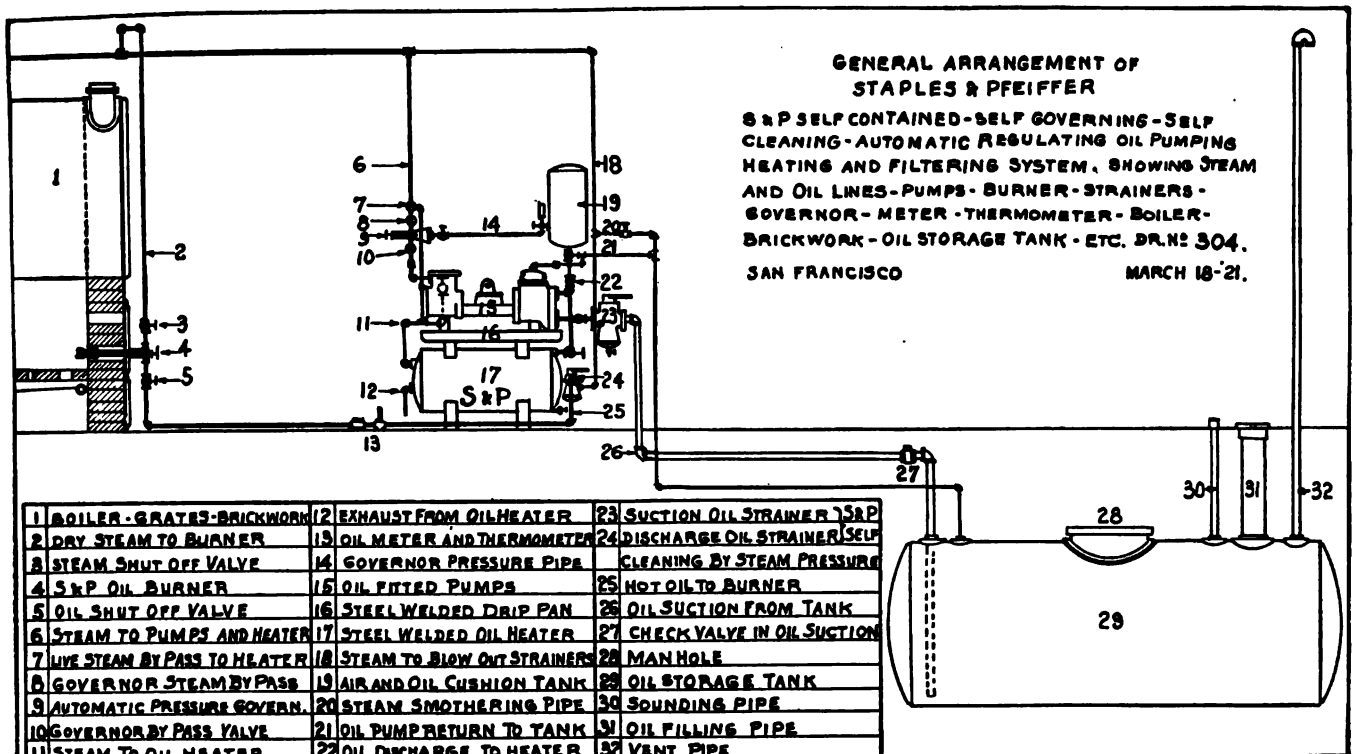
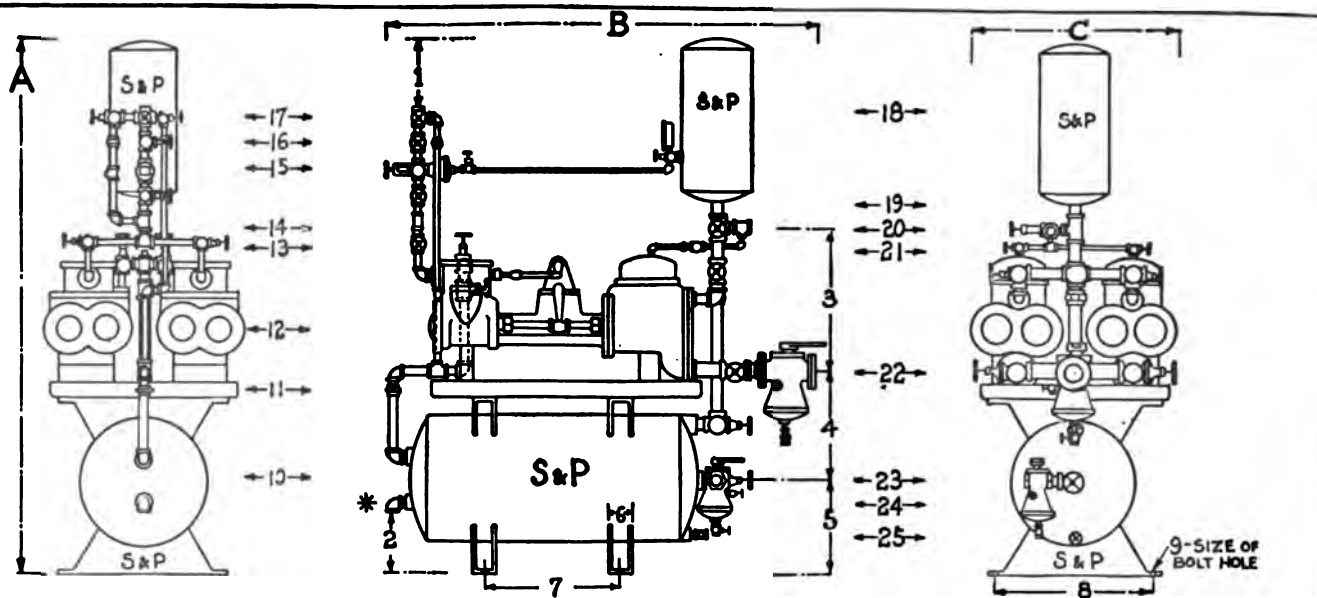

GENERAL ARRANGEMENT OF
STAPLES & PFEIFFER
S & P SELF CONTAINED - SELF GOVERNING - SELF CLEANING - AUTOMATIC REGULATING OIL PUMPING HEATING AND FILTERING SYSTEM, SHOWING STEAM AND OIL LINES - PUMPS - BURNER - STRAINERS - GOVERNOR - METER - THERMOMETER - BOILER - BRICKWORK - OIL STORAGE TANK - ETC. DR. Nº 304.
SAN FRANCISCO
MARCH 18-'21.
S&P
1 BOILER - GRATES - BRICKWORK
2 DRY STEAM TO BURNER
3 STEAM SHUT OFF VALVE
4 S & P OIL BURNER
5 OIL SHUT OFF VALVE
6 STEAM TO PUMPS AND HEATER
7 LIVE STEAM BY PASS TO HEATER
8 GOVERNOR STEAM BY PASS
9 AUTOMATIC PRESSURE GOVERN.
10 GOVERNOR BY PASS VALVE
11 STEAM TO OIL HEATER
12 EXHAUST FROM OIL HEATER
13 OIL METER AND THERMOMETER
14 GOVERNOR PRESSURE PIPE
15 OIL FITTED PUMPS
16 STEEL WELDED DRIP PAN
17 STEEL WELDED OIL HEATER
18 STEAM TO BLOW OUT STRAINERS
19 AIR AND OIL CUSHION TANK
20 STEAM SMOTHERING PIPE
21 OIL PUMP RETURN TO TANK
22 OIL DISCHARGE TO HEATER
23 SUCTION OIL STRAINER
24 DISCHARGE OIL STRAINER
SELF CLEANING BY STEAM PRESSURE
25 HOT OIL TO BURNER
26 OIL SUCTION FROM TANK
27 CHECK VALVE IN OIL SUCTION
28 MAN HOLE
29 OIL STORAGE TANK
30 SOUNDING PIPE
31 OIL FILLING PIPE
32 VENT PIPE

FIG. 220.



SYSTEM SIZE	PRICE LIST	BOILER H.P.	SHIPG. WGHT.	PUMP SIZE	CAPACITY PR. MIN. UP	HEATER DIAM.	HEATING SURFACE	STEAM SIZE	EXHAUST SIZE	DISCHG. SIZE	SUCTION SIZE	HIGHT A	LENGTH B	WIDTH C	PIPING CENTERS 1	2	3	4	5	BASE CENTERS 6	7	8	9
B	$ 800	250	1000	3-2-4	1 GAL	16"	10 SQ. FT	3/8"	3/4"	1"	1½"	60"	50"	24"	4"	6"	20"	8"	12"	3"	18"	15"	7/8"
C	$ 1000	500	1500	4½-2¾-4	2½ "	16"	15 "	½"	1"	1"	2"	65"	56"	30"	5"	6"	25"	9"	12"	3"	18"	15"	7/8"
D	$ 1400	1000	2500	5¼-3½-5	5 "	16"	30 "	¾"	1¼"	1½"	2½"	70"	70"	34"	6"	6"	22"	16"	12"	3"	22"	15"	7/8"
E	$ 2000	1500	3000	6-4-6	7½ "	16"	45 "	1"	1½"	1½"	3"	76"	72"	36"	4"	6"	24"	18"	12"	3"	22"	15"	7/8"
F	$ 3000	2500	4000	7½-5-6	12½ "	16"	75 "	1½"	2"	2"	4"	78"	78"	40"	2"	6"	24"	20"	12"	3"	22"	15"	7/8"

10	OIL HEATER - STEEL WELDED -	16	GOVERNOR STEAM BY PASS	22	SUCTION STRAINER - SELF CLEANING -		
11	PAN - STEEL WELDED -	17	LIVE STEAM BY PASS TO HEATER	23	DISCHARGE STRAINER - SELF CLEANING -		
12	TWO PUMPS - OIL FITTED -	18	AIR TANK - STEEL WELDED -	24	LIVE STEAM CON. TO BLOW OUT STRAINERS		
13	STEAM TO PUMPS AND HEATER	19	AUTOMATIC OIL RELIEF VALVE	25	BLOW OFF FOR WATER AND OIL SEDIMENT		
14	EXHAUST BY PASS TO ATMOSPHERE	20	OIL RETURN TO TANK DIRECT	*	EXHAUST TO HOTWELL OR STEAM TRAP		
15	AUTOMATIC GOVERNOR - BRASS -	21	GAS RELIEF BY PASS TO TANK	HEATER AND PARTS TESTED TO 400 LBS. PR. SQ. IN.			

STAPLES & PFEIFFER

GENERAL ARRANGMENT AND APPROXIMATE DIMENSIONS OF OIL BURNING SYSTEMS

SAN FRANCISCO Nov 1920

1920 MODEL DR. Nº 500

FIG. 221.

the thermometer read lower than the true temperature because it was located in a dead space in the pipe where the oil cooled off.

Almost as important as the oil-pipe system is the steam pipe carrying steam to the burners. All steam-atomizing oil burners give better results and use less steam when supplied with dry steam; because, if there is moisture present, not only is this moisture wasted in the furnace, but part of the atomizing effect of the burner is wasted in atomizing this water, and part of the heat in the furnace is lost in superheating the moisture to stack temperature.



FIG. 222.—Staples & Pfeiffer gravity type crude oil burner, for oil pressures from 1 lb. up, or 2 ft. elevation up, and for crude oil with steam atomising.

The connection for the steam header to the burners should be taken from the top of the principal steam main, and, in turn, the steam branches to the individual burners should be taken from the top of the burner steam header. Provision must be made for draining this header. It is well known that moisture in steam does not affect appreciably the operation of a steam pump, so the author advocates the practice of taking the pump steam connection from the bottom of the burner header, which will automatically drain out the moisture through the pump; where this is not practicable, a steam trap should be used. The steam header should be insulated, with the exception that it is not customary to cover the branches to the burners.

A convenient and sightly method of locating the oil and steam headers, where there are several boilers in a row, is in a trench

just in front of the boilers; the steam and oil branches to the burners should be placed so as not to interfere with closing the ashpit doors.

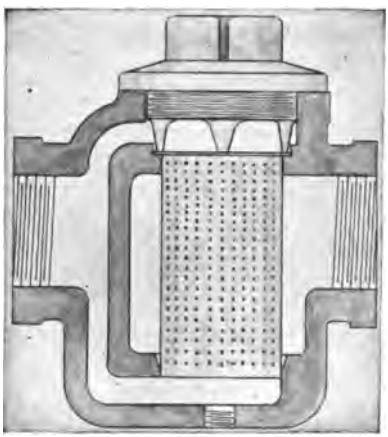


FIG. 223.—The oil strainer of A. M. Lockett & Company, New Orleans, La.

A frequent source of trouble with oil burners, sometimes difficult to diagnose, is the obstruction of the burner steam outlet by scale from the interior of the pipe; new pipe often



FIG. 224.—The W. N. Best "Calorex" oil regulating cock. This regulating cock has a v-shaped, knife-edge, opening in the plug which not only has a shearing action on heavy liquid fuels, but enables the operator to secure the desirable adjustment.

has loose mill scale inside, and old pipe sometimes has sand or dirt. The remedy is to rap the pipe well with a hammer, to loosen the dirt or scale, and then to blow it out with steam or com-

pressed air; this, of course, should be done before the burners are connected.

In steam plants where the steam pressure is subject to consid-



FIG. 225.—The oil regulating cock, Hammel type, manufactured by the Hammel Oil Burning Equipment Co., New York, N. Y.

erable variation, due to the character of the load, it will be found desirable to install in the burner main steam line a reducing valve set at the lowest pressure to which the boiler pressure

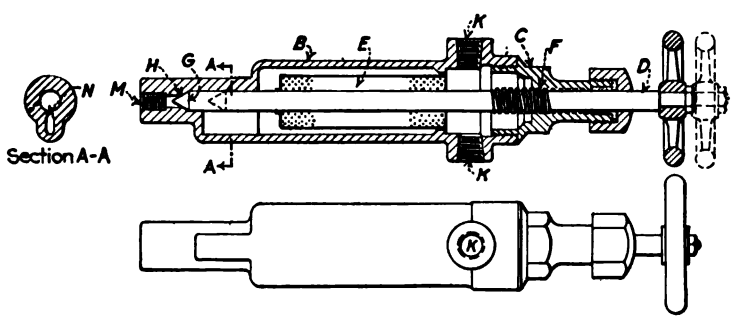


FIG. 226.—Lockett oil regulating valve for burners.

falls; this will make the operation of the burners much more satisfactory and will save steam. It is assumed that in such cases the minimum steam pressure is sufficient to insure proper

atomizing. In plants where over 160-lb. steam pressure is carried, a reducing valve set at 150-lb. pressure will give better results than full boiler pressure, and will save steam as well.

THE OIL BURNER AND FURNACE

The fuel oil has been brought up to the boiler, heated and ready to burn; the question of the oil burner has purposely been left until the last, principally to show the prospective user of oil that there are several other things to be considered than the burner. It is a popular misconception that all that is necessary to secure results in oil burning is a good oil burner, and unfortunately this idea is fostered by certain manufacturers, especially ones with burners having "patient insides," who are more interested in the sale of their particular apparatus than in promoting the use of oil in a sound way.

The author, as the designer of a successful oil burner, is, with other engineers interested in encouraging the use of oil in a broader way, desirous of correcting this misconception. This false idea arises from the fact that the name "oil burner" is a misnomer, because the so-called burner does not burn the oil, but merely atomizes it; the furnace burns the oil, and therefore the design of furnace is as important as or even more so than the burner.

The requisites of a good oil burner are: for efficiency—economy in the use of steam for atomizing, close regulation, and the production of a flame of such shape as to make possible the reduction of the air supply to a minimum, and hence high furnace efficiency; for satisfactory operation—simplicity, ease of operation, minimum of wearing parts, minimum of adjustments, and ease of replacing wearing parts.

By far the greater part of the oil burners used for stationary boiler work are of the steam atomizing type; the use of air for atomizing is practically obsolete, except for special purposes, such as metallurgical work; and the use of mechanical atomizer burners is practically confined to marine work, although it is possible that this type will eventually be developed for stationary work.*

* Since this was written, very important developments in mechanical oil-burning have been made by one of the large boiler manufacturers in the way of large burner and boiler capacities with very high efficiencies and without injury to boilers or brickwork (see illustration giving curves of capacity and efficiency with Lockett mechanical burners; also illustration of burner and boiler furnace, Figs. 242, 243 and 244).

The function of the steam-atomizer burner being the purely mechanical one of breaking up the oil due to the impact of the steam on the oil, there naturally is an infinite variety of such devices—in fact, nearly every engineer who burns oil has his own idea of what constitutes a burner. Steam-atomizer burners may be divided into two general classes: those that mix the oil and steam inside, and those that mix outside the burner; both inside and outside mixer burners are made in round-flame and flat-flame types. A few representative types of these various burners are shown in the illustrations (see Figs. 229 and 231).

The principal disadvantages of the mechanical burner up to this time have been: high oil pressure required, narrow range of load, small capacity per burner, and high draft necessary. The Babcock and Wilcox burner is extremely interesting in that it overcomes largely the first three objections, though still requiring high draft, so as to limit its use for that reason. It is very probable, however, that the next development will be the reduction of draft necessary for high capacity. Through the courtesy of the manufacturers we are able to give below a description of this burner.

The purpose of the mechanical atomizer is to produce an intimate mixture of air and oil, the latter in such a finely divided condition as to be a mist or cloud. The air and oil are mixed in the proper proportions to meet the conditions of load under which the boiler is operating, and the adjustments to meet different conditions of load are made easily and quickly. The atomization of the oil permits combustion to proceed more quickly than it can where oil is injected into a furnace in a long jet and the atomization also utilizes a greater proportion of the volume of the furnace for combustion.

A conical cast iron casting, 1, is placed in the front wall of the boiler setting (Fig. 255) as an orifice through which the air and oil are admitted to the furnace. The main register casting, 2, is fitted with automatic doors, 3, by which the quantity of air supplied to the burners may be regulated or shut off entirely. These doors are so designed that they will close automatically in case of a flare-back in the furnace or the bursting of a boiler tube, thus protecting the fireman who may be standing in front of the boiler. A cover plate, 4, is attached to the front of the register casting, and a radiation guard, 5, is held between them.

The operation of the automatic air doors, 3, is controlled by

four cams, 6, forming part of a spider casting which can be rotated by the handle, 7. By moving the handle to the extreme right of the slot through which it slides, the position shows in the engraving, all the air doors are closed; by moving it to the left the doors are gradually opened.

Passing through the center opening in the cover plate, 4, is a hollow cylindrical distance piece having at its outer end a quick detachable coupling, 9, and yoke, 10. To the other end of this distance piece is fastened an aluminized-steel conical shaped impeller plate, 11, for regulating the distribution of air at the nozzle of the burner. Passing through the distance piece is the mechanical atomizer, 13, which is held in place and connected to the fuel oil supply lines through the coupling, 9, and yoke, 10, thus making the atomizer, 13, the distance piece and the center impeller, 11, a rigid unit when in operation.

The distance piece is so designed that it may be moved along its axis, thus moving the impeller plate, 11, in and out with reference to the cone, 1, and decreasing or enlarging at will the clear area for the passage of air around the outside of the impeller plate. The distance piece is held in place by a set screw, 12.

The atomizer ends in a burner which imparts a rotary motion to the oil as it emerges in a conical spray. The burner ejects this spray through a central opening in the impeller plate, 11, which plate has blades like those of a fan to give a rotary motion to the air as it enters the furnace around the burner tip. The cone, 1, also has blades which give a whirling motion to the air entering around the edge of the impeller plate, this air being directed along the axial line of the burner by the walls of the truncated cone. The operator controls the furnace conditions by the adjustment of the boiler dampers, the air supply of the burners, and the pressure and temperature of the oil.

In general, except in particular cases to fit special furnace conditions, the flat-flame or "fish-tail" burner is preferable to the round-flame type for three very good reasons. First, flat-flame burners use less steam for atomizing than round-flame burners; this is probably because the flat shape of the flame exposes a greater area of surface to the air in the furnace, in proportion to the flame volume, allowing a better chance for combustion in the small unit of time during which a particle of oil is passing through the flame, and hence not requiring (for good results) atomizing into as small particles as in the more



FIG. 227.—G. E. Witt Company oil regulating valve.

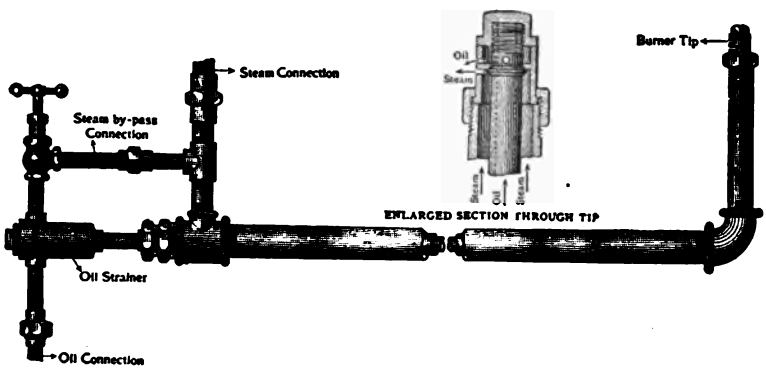


FIG. 228.—Flat-flame outside-mixer oil burner. Babcock & Wilcox Company's "Peabody Front Shot No. 2."

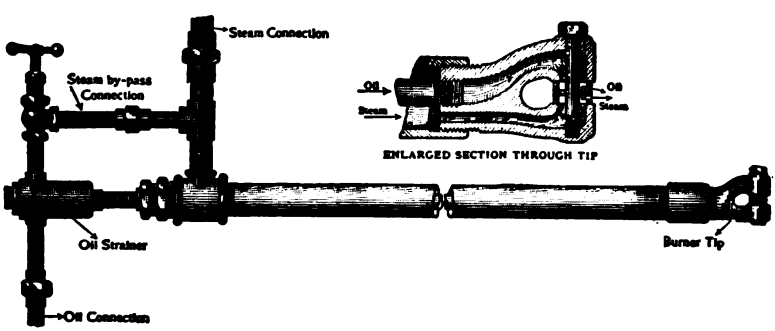


FIG. 229.—Flat-flame outside mixer oil burner. Babcock & Wilcox Company's "Peabody Back Shot No. 1."

compact flame from the round burner. Second, the flame from a fish-tail burner is flat, uniform in thickness, and may be made to lie a few inches above the grates, so that, by proper arrangement of air openings under the flame, it is possible to distribute

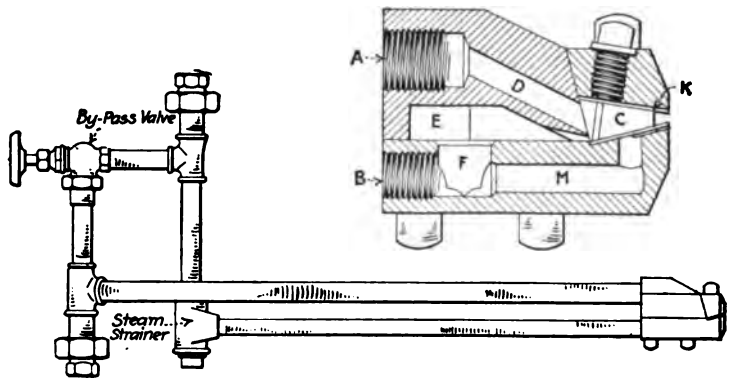


FIG. 230.—Flat flame, inside and outside mixer type, Hammel Oil Burning Equipment Company, "Front Shot."

the air where it is wanted and exclude it where it is not wanted, at the sides of the flame. Third, because of the concentrated and dense flame from a round burner, there is a blow-torch action which may injure the boiler and which it is customary to

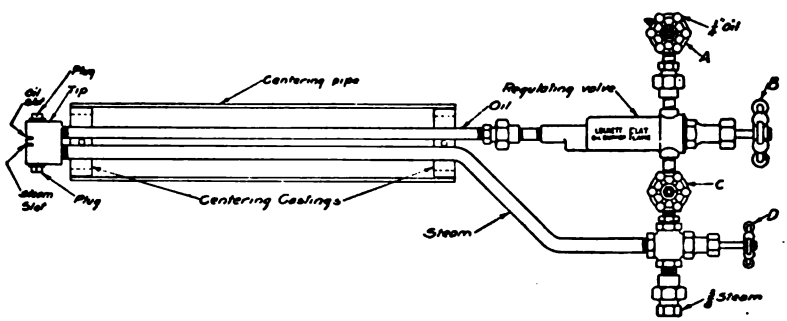


FIG. 231.—Flat-flame, outside-mixer oil burner. A. M. Lockett & Company, Ltd., "Front Shot No. 2."

relieve by shooting against a firebrick target wall, which also helps to atomize the oil; a target wall, besides being an extra expense, and reducing the furnace volume, is likely to deflect the flame against some other part of the boiler. Fish-tail burners

require no target wall and, due to smaller quantity of steam for atomizing, give a much "softer" flame.

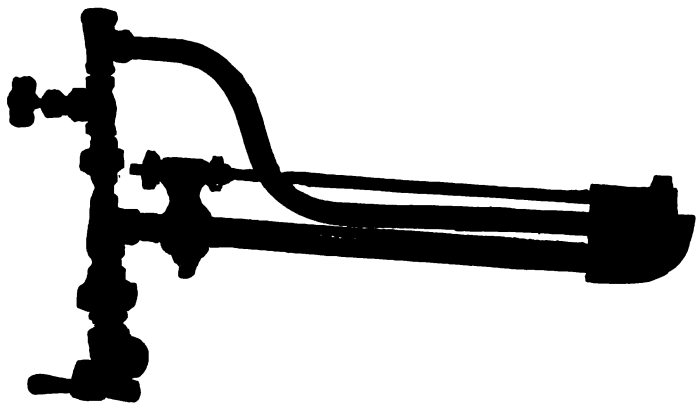


FIG. 232.—The W. N. Best "Calorex" burner mounted for boilers. The burner is connected to piping of sufficient length to go through the front setting of the boiler. By means of the by-pass valve any foreign substance that may enter the oil pipes can be blown out. The atomizer lip is hinged and held tight against the body of the burner, but means are provided for raising the lip to blow out the atomizer pipe in case any foreign substances, such as scale, red lead, etc., should lodge therein. This can be accomplished quickly without removing the burner from the boiler. *A* is the pass valve; *B* is the oil regulating cock; and *C* is the oil or tar connection.

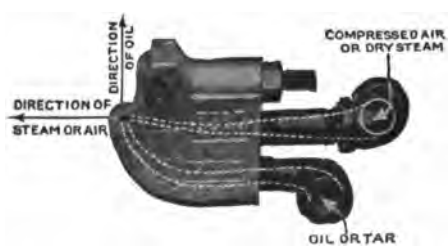


FIG. 233.—The W. N. Best "Calorex" burner unmounted. The air or steam meets the oil at right angles, thus thoroughly atomizing the oil externally, which prevents clogging or carbonizing, the burner always being kept clean. By releasing the set screw in the yoke and raising the lip, any obstruction that might find its way through the air line can be blown out. Air or dry steam from 15 pounds up can be used to atomize the oil. This type of burner can be fitted to throw either a long narrow flame or a fan-shaped flame, 9 feet wide, thus doing away with the necessity of using more than one burner to any fire-box or furnace that is 9 feet or less in width.

The amount of steam used by the burner for atomizing, the real criterion of burner "efficiency," varies considerably.

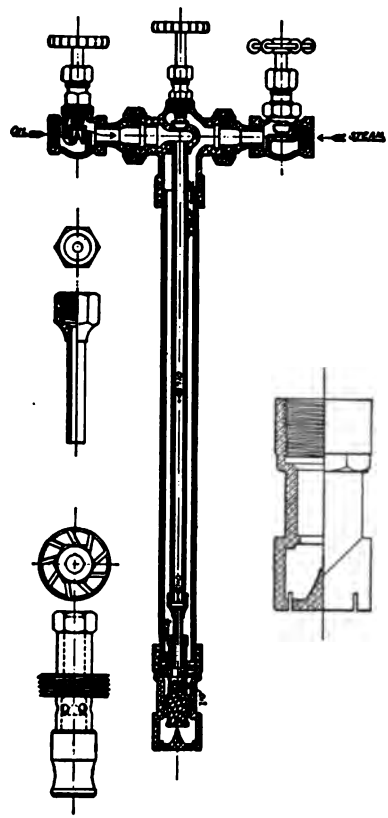


FIG. 234.—Flat-flame, inside-mixer oil burner and details. G. E. Witt Company's "Little Giant."

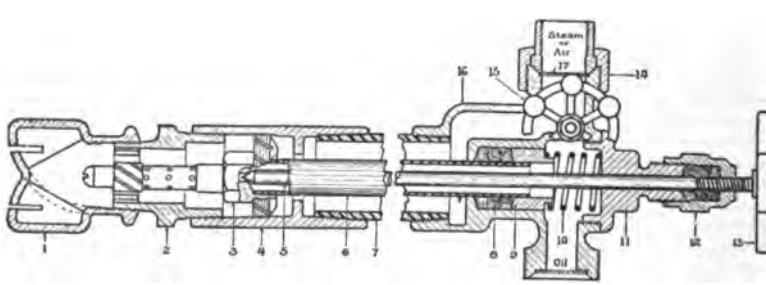


FIG. 235.—Flat-flame, inside-mixer oil burner, Staples & Pfeiffer's No. 4.

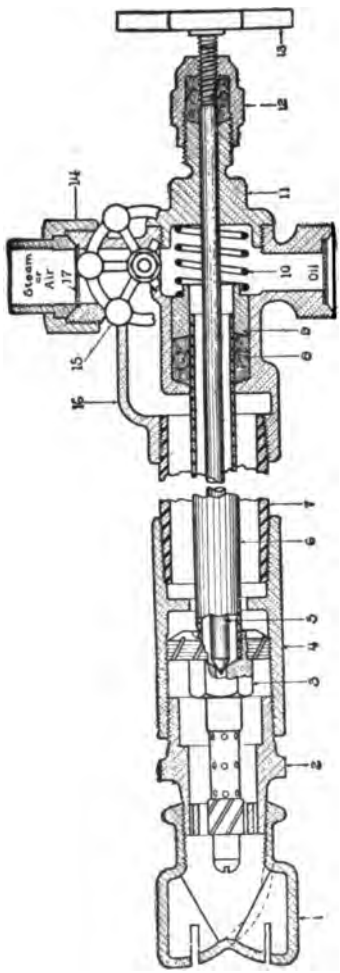


FIG. 236.—The Staples & Pfeiffer oil burner, needle valve type, 1910 model. The parts shown are as follows: tip, bushing, mixer (steam or air), sleeve, valve rod, oil pipe, steam pipe, packing (box of cut rings), gland, spring, bonnet, nut, wheel, union, by-pass, body, screen (dozen), and wrench (for mixers).

The better flat-flame burners use as little as 1½ or 2 per cent of the steam generated by the boiler; and the round-flame, from 2½ to 7 per cent. It should be noted that a careless fireman

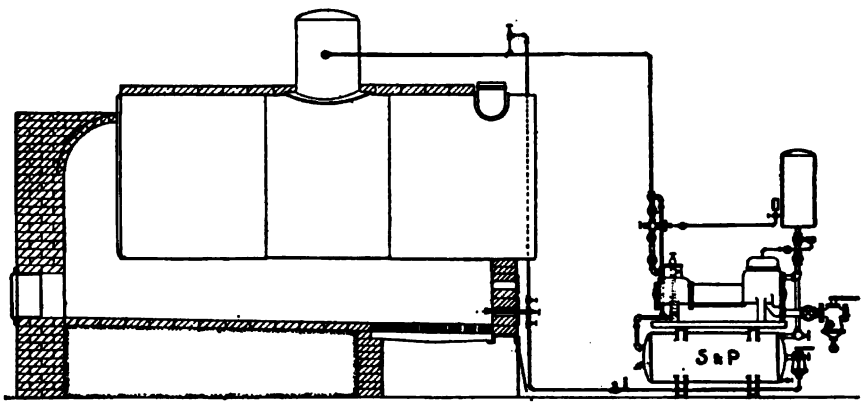


FIG. 237.—Tubular boiler fitted with Staples & Pfeiffer oil burner system.

can easily waste a great deal of steam at the burner, for beyond the amount required for efficient atomizing any surplus does no good but is entirely wasted.

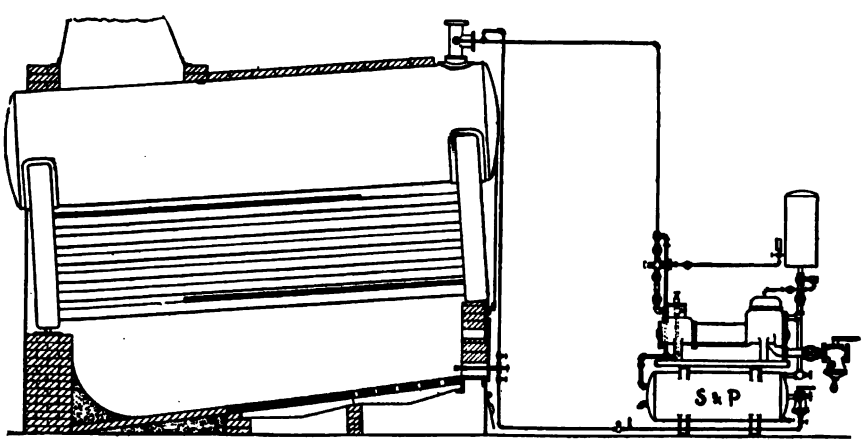


FIG. 238.—Heine boiler fitted with Staples & Pfeiffer oil burner system.

It may be mentioned here that there are on the market several makes of successful automatic devices for controlling the amount of steam and oil to a burner, this control being made to correspond to the rise and fall in steam pressure; these devices, while theo-

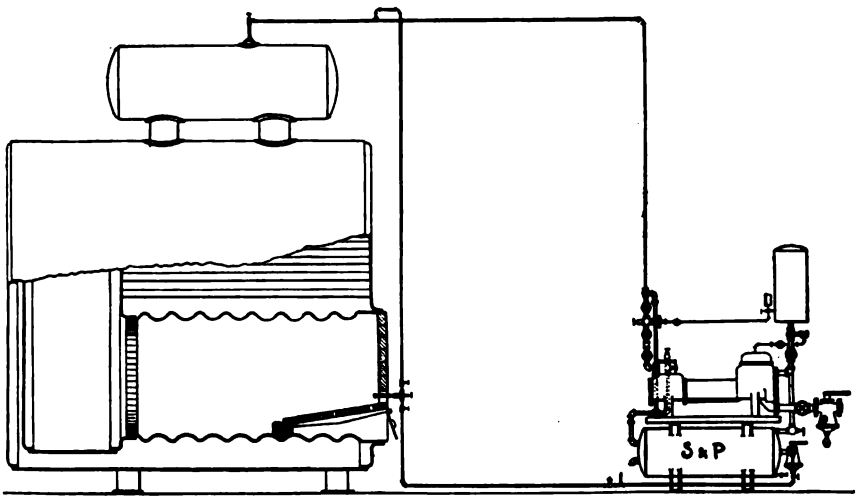


FIG. 239.—S. M. boiler fitted with Staples & Pfeiffer oil burner system.



FIG. 240.—Round flame, inside mixer oil burner of the Tate, Jones & Company, Pittsburgh, Pa.

retically perfect, and used to some extent, have the element of danger present in all automatic devices for steam boiler control, in that the operator may get careless and rely too much on the automatic equipment. This argument, of course, would apply to any other automatic device, and the "mechanical fireman" has shown good results under proper supervision.*

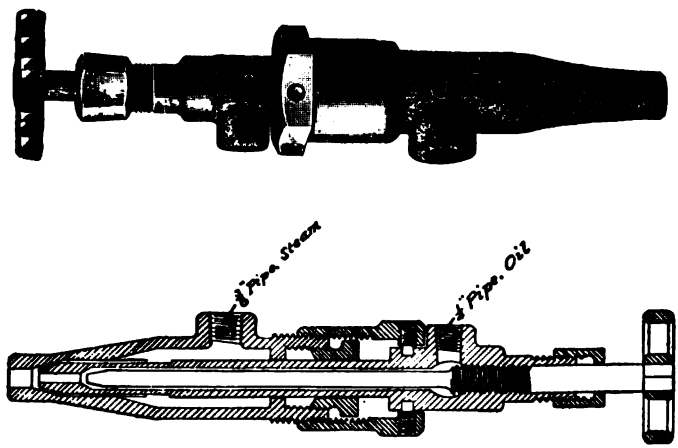


FIG. 241.—Round-flame, inside-mixer oil burner, Reid type, No. 3.

THE OIL FURNACE

Because of the fact that almost every manufacturer of oil burners for steam boilers has furnace designs for various types of boilers, it is manifestly impossible to describe all types of furnaces, and accordingly there is given in the illustrations a number of furnaces for various types of boilers, to present an idea of the principles given below rather than to present all the well known furnaces. Because of the superiority of the fish-tail or flat-flame burner, the furnace designs given are selected with the idea of showing various types of furnaces for this class of burner.

The so-called furnace being really the "oil burner," as explained, its design is of prime importance and must be carefully considered as regards:

* Since this was written, considerable progress has been made in automatic oil-firing and there are now on the market several excellent systems of automatic steam, oil and feed water control for oil-fired boilers. In the author's judgment, these systems are more applicable to the larger plants which have high grade operators who understand automatic appliances and can keep them adjusted.

1. The materials of which it is made;
2. The shape with respect to the type of boiler;
3. The location of the oil burner or burners;
4. The air admission with respect to the shape of burner flame; and
5. The volume with regard to the capacity required from the boiler.

1. While the life of a proper oil furnace is longer than for a coal-fired one, because of more uniform temperature, it must be remembered that this temperature is considerably higher than for coal, and only the best grade, most refractory firebrick should

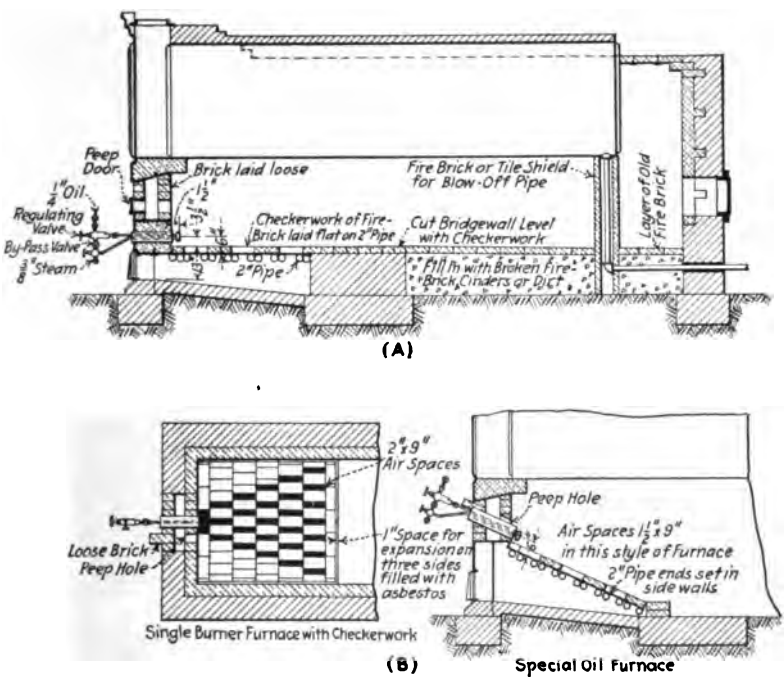


FIG. 242.—Horizontal return tubular boiler, fitted with Lockett oil burner.

be used; the high temperature causes greater brickwork expansion, and better mason work is necessary. It is sometimes essential to use greater thickness of firebrick lining, with more bonding than for coal; in particular, furnace linings should be laid with the minimum thickness of fireclay joints (and high temperature fireclay should be used).

2. The shape of the furnace should be such as to cause the the minimum direct impingment of flame on the tubes, to avoid tube trouble, as well as the longest possible travel of the flame

before it strikes the comparatively cool surface of the boiler; in general, it is also desirable to have a furnace that can be converted, if necessary, to coal burning without extensive reconstruction, when there is a possibility of wanting to burn coal at some future time. There follows an explanation of typical arrangements for the more usual types of boilers.

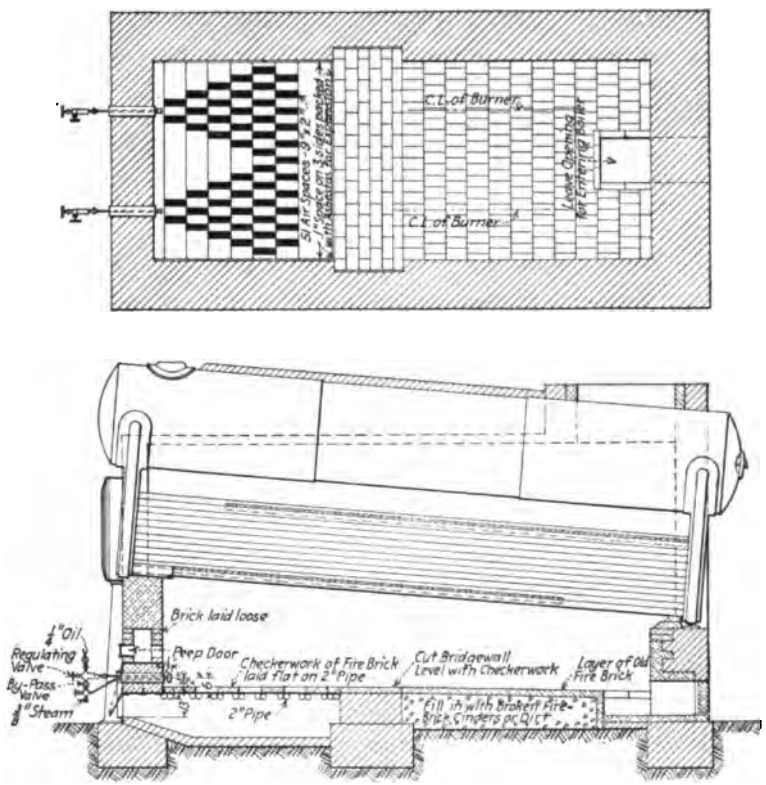


FIG. 243.—Boiler of horizontal baffle type, such as Heine, fitted with Lockett burners.

Horizontal Return Tubular Boiler.—This type of boiler is easy to adapt to oil without much modification of the coal furnace. Figure 242, arrangement *A*, shows such a furnace: the bridge wall is cut flush with the grates, the blowoff pipe is protected, and a front shot burner is set in the firing door. Figure 242, arrangement *B*, shows another type sometimes used; its advantage is the saving of grates and bridgewall, with somewhat greater furnace volume.

Horizontal Water Tube, Heine Type.—The same remarks apply to this type as to the return tubular boiler, and the arrangement is identical (see Fig. 243).

Babcock & Wilcox Type.—Vertical baffle boilers give the choice of two types of furnaces: (1) Where the front-shot burner is set in the firing door, shooting towards the bridge wall (see Figs. 244 and 245); this arrangement is cheaper, and, where the

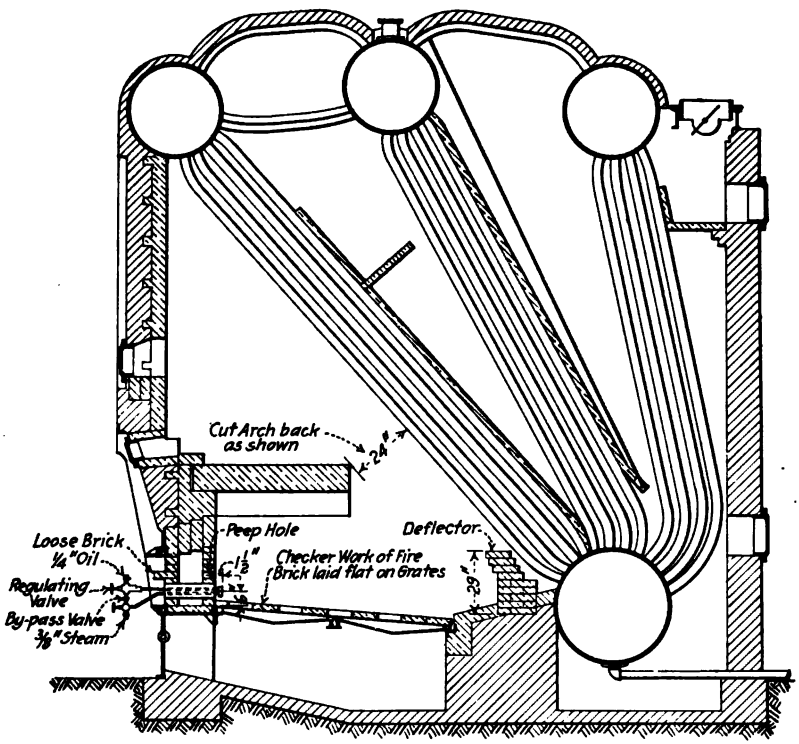


FIG. 244.—Lockett front shot burner in Stirling boiler.

tubes are free from scale and the load on the boiler is not great, gives good results. (2) If it is desired to operate at high boiler capacity, or if the tubes are subject to internal scale, the impingment of flame, due to the inherent short furnace, will cause burning of the tubes and the back-shot type of burner and furnace should be used (see Figs. 247 and 248). The back-shot burner permits the use of a longer furnace, with the flame shooting against the front wall of the boiler, instead of against the tubes.

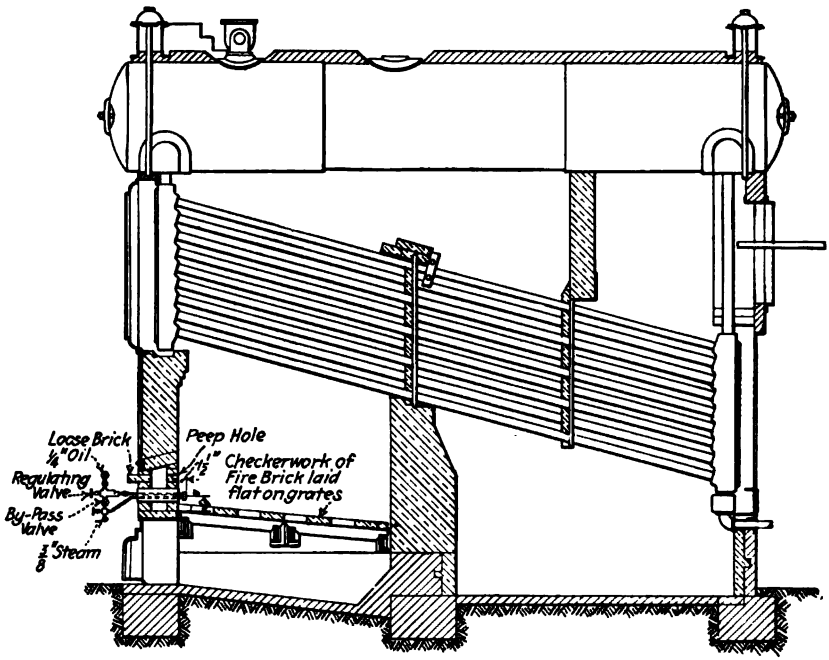


FIG. 245.—Lockett front shot burner in B. & W. boiler.

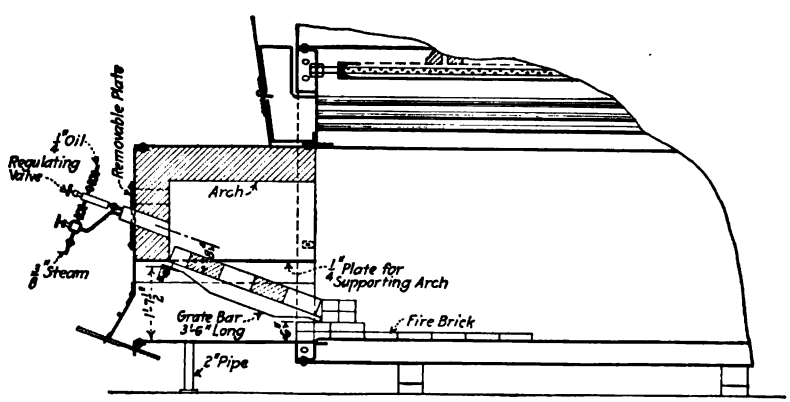


FIG. 246.—Lockett flat flame oil burner under Scotch marine boiler.

Figure 250 shows the Peabody patented furnace of the Babcock & Wilcox Co., wherein the bridge wall is moved back to give about 10 ft. furnace depth. Figure 249 shows the Hammel furnace, where the additional depth is obtained by setting the burner in a pocket in the bridgewall.

The Stirling Boiler.—The same general remarks apply to the Stirling as to the Babcock & Wilcox furnace; in both cases,

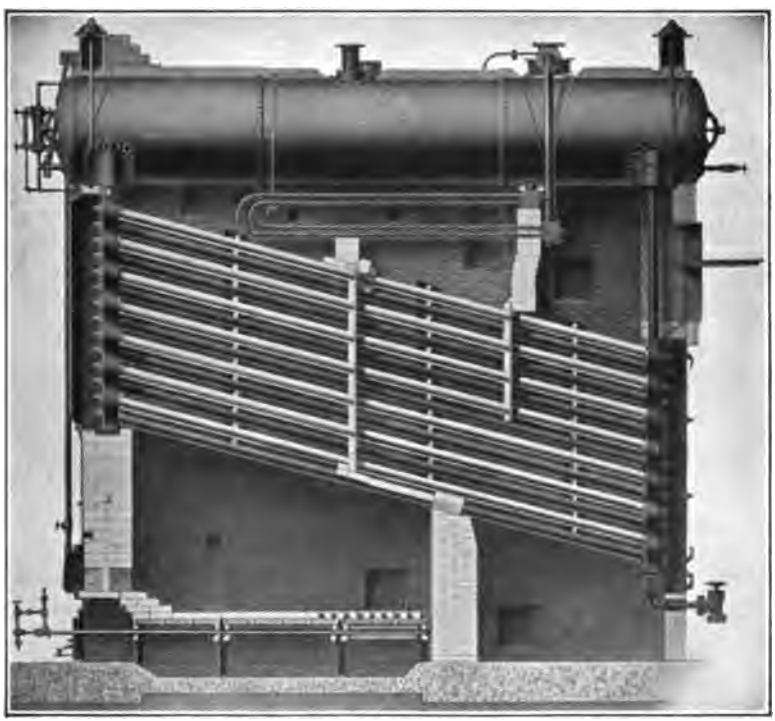


FIG. 247.—Babcock & Wilcox boiler, equipped with a Peabody oil furnace and Peabody back shot oil burner.

larger capacity and less liability to tube trouble result from the back-shot burner. Figure 249 shows one type of Stirling back-shot furnace. It will be noticed that the arch in the furnace is omitted. Still better results are got if the boiler is arranged with a flush-type front, instead of the standard undercut arrangement. When using the front-shot burner, the arch is left in, but cut back until its edge is about 24 in. from the tubes; a

deflector wall is built on top the bridge wall, about 24 in. high (see Fig 245).

3. The location of the burner has been given for the several standard types of boilers; the number of burners required naturally varies with the manufacturer's rating of the burner and the load to be carried. It may be stated, in general, that most of

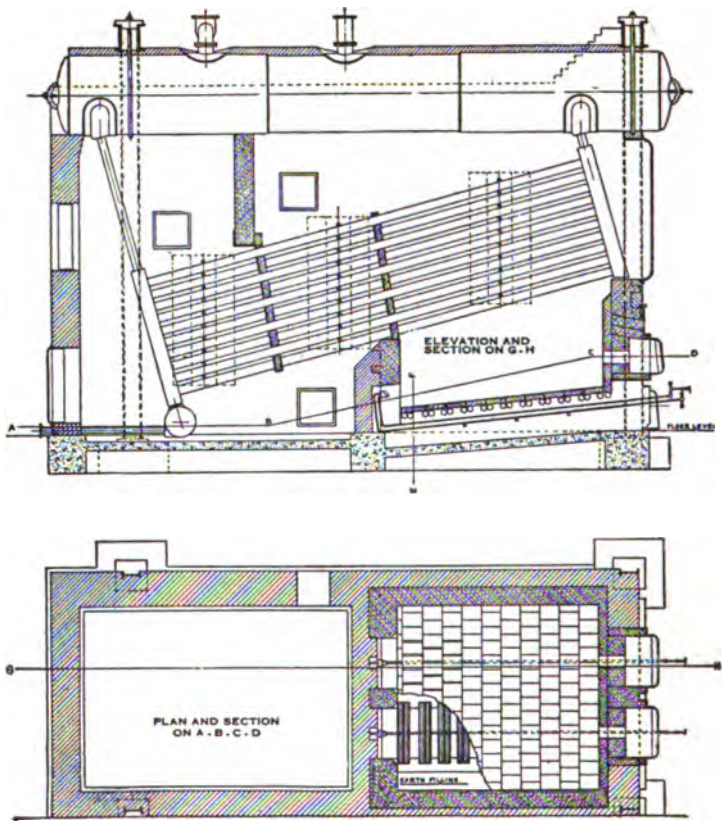


FIG. 248.—Vertical baffle boiler, fitted with Hammel furnace and Hammel back shot burner.

the flat-flame burners are of such capacity that one in each hand-firing door of the furnace will give good results; this means about 100 to 200 hp. per burner. It is really a question of flame distribution in the furnace; and the more burners used per boiler, the less the concentration of flame at any one point. It is well to take up each particular case with the burner manufacturer.

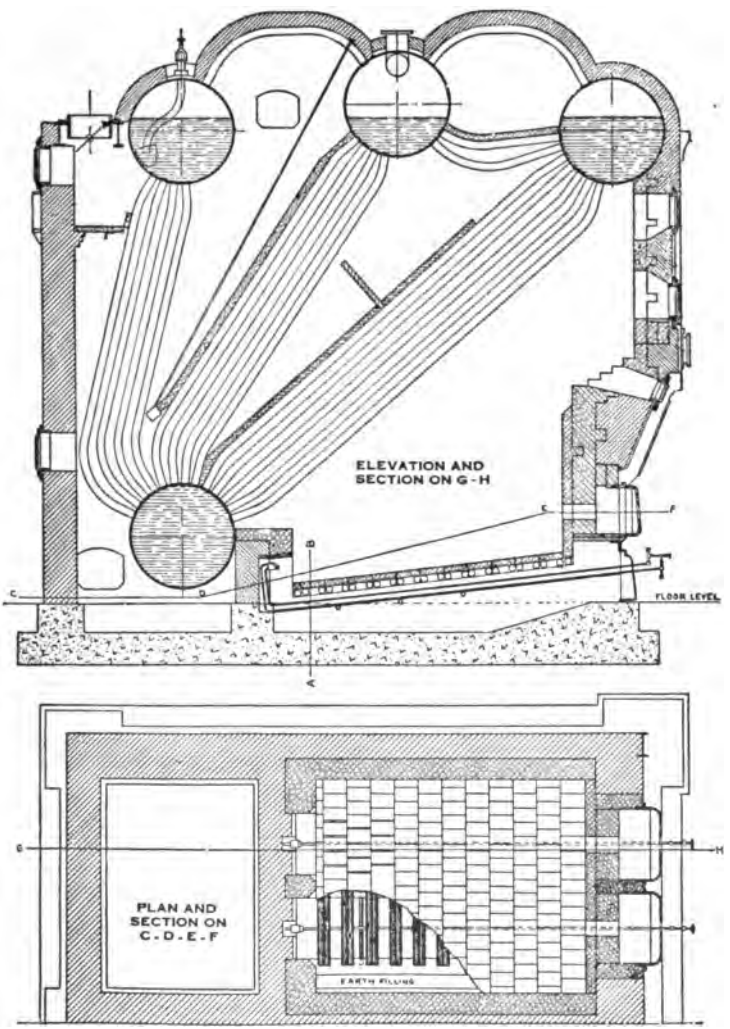


FIG. 249.—Stirling boiler, fitted with Hammel furnace and Hammel oil burner.

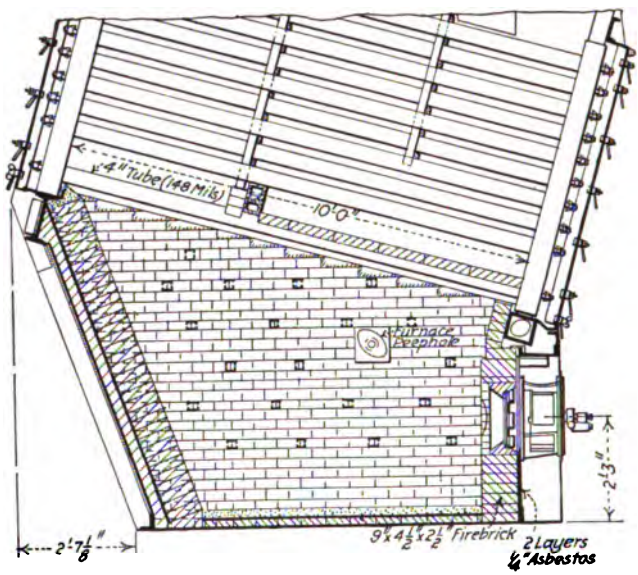


FIG. 250.—Peabody mechanical atomizer oil burner on the front plate of a Babcock & Wilcox boiler.

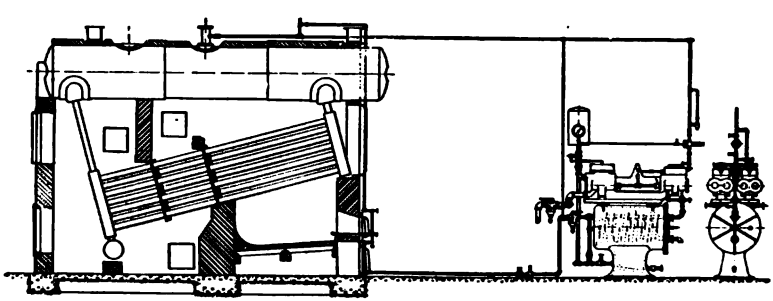


FIG. 251.—Vertical baffle water-tube boiler, fitted with a Staples and Pfeiffer burner.

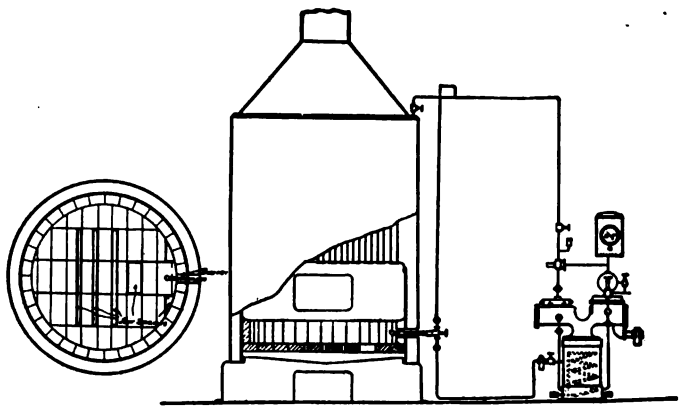


FIG. 252.—Vertical boiler, fitted with a Staples and Pfeiffer burner.

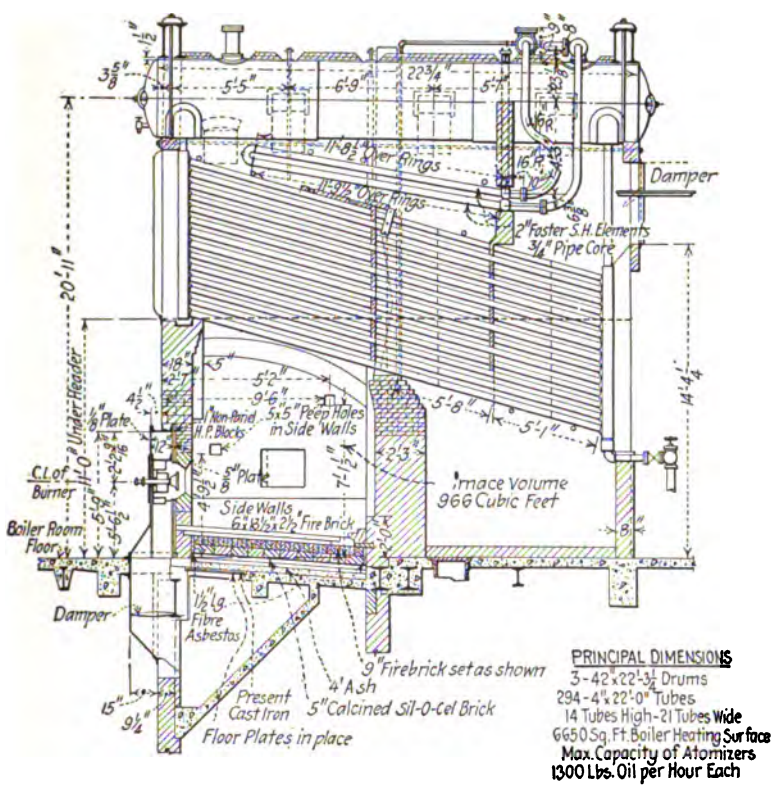


FIG. 253.—Boiler and furnace design, Savannah installation.

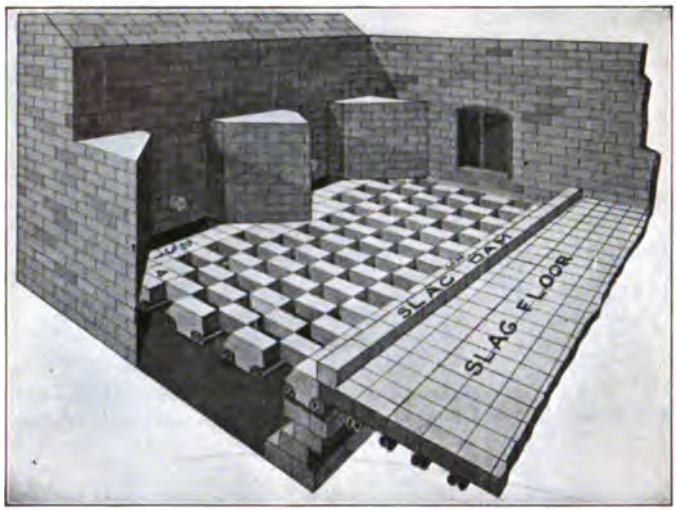


FIG. 254.—Turner hearth tile. (*Boiler Equipment Service Company, Atlanta, Ga.*)

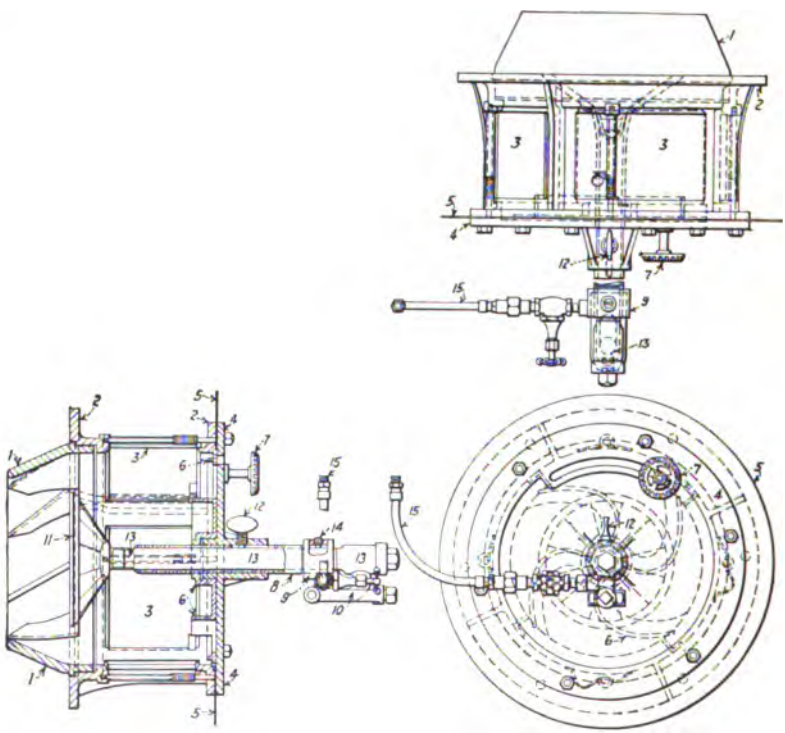


FIG. 255.—Assembly of Peabody burner and firing front, Cuyama design, for either forced or natural draft.

4. The air admission to the furnace is very important if efficient results are to be secured; air is wanted under the flame, and nowhere else if high CO_2 is desired. The usual admission of air is through a "checker work" of firebrick laid on grate bars or pipes, and the shape of the group of checkerholes should be fan-shaped, like the shape of the flame, and directly underneath; the remaining surface of the furnace should be covered closely with firebrick and all cracks sealed with fire clay. As the

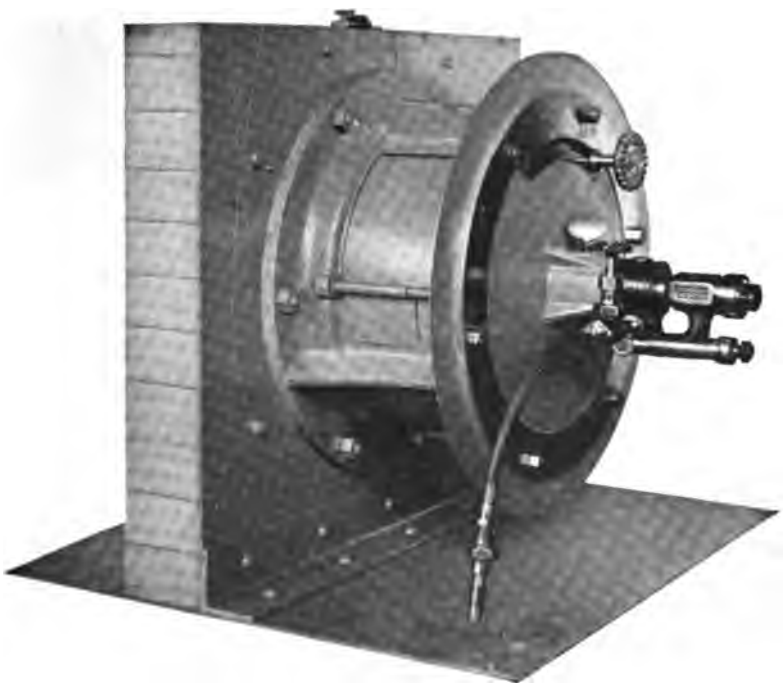


FIG. 256.—The Babcock & Wilcox mechanical atomizer for fuel oil.

checker-work gets hot, there is a considerable expansion, which should be provided for by an expansion joint around the edge of the furnace, packed with asbestos to prevent air leaks.

The area of holes in the checkerwork should be proportioned properly to the draft in the furnace and to the load on the boiler. For normal conditions, where the ashpit doors are open, and the furnace draft is about 0.10 in. of water, the area should be about 2 sq. in. net per horsepower. Where the checkerwork is laid on

ordinary grate-bars which obstruct about 50 per cent of the area, the gross area then will be about four square inches per horsepower.

Ordinary fire-brick laid on pipes or bars are apt to be displaced or to fall out. A decided improvement is seen in several types of interlocking hearth tile made especially for air checker-

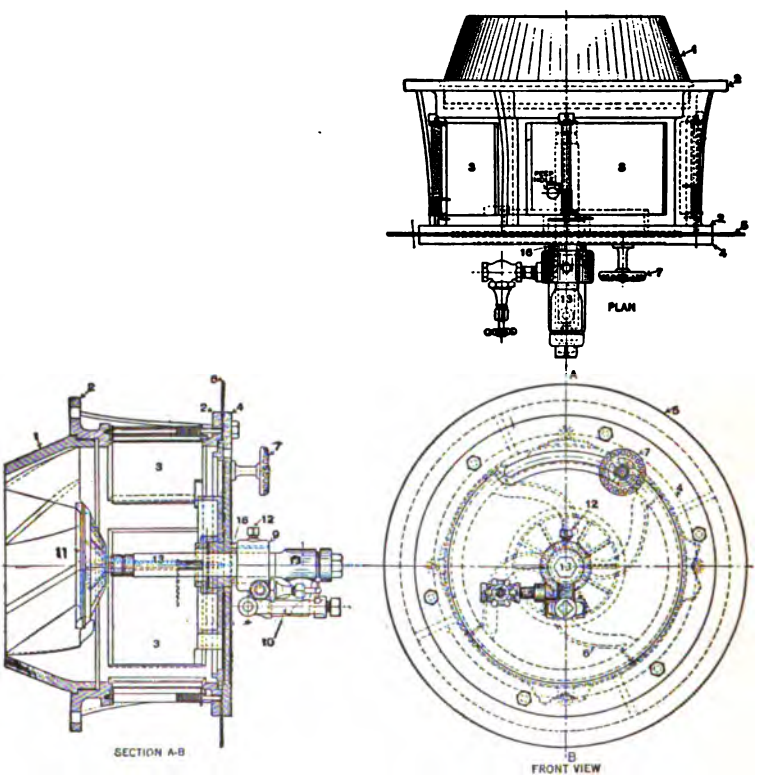


FIG. 257.—Details of the construction of the Babcock & Wilcox mechanical atomizer for fuel oil.

work in oil furnaces, a good example of which is the Turner tile (see Fig. 254).

5. The maximum capacity from a boiler will depend on the furnace volume as one factor; but there are so many other considerations entering into the forcing of a boiler to very high ratings, that such cases preferably should be taken up with the boiler manufacturer. For moderate overloads, which will cover the

great majority of cases, where, for example, the boilers are to be run at loads not over 150 per cent of rating, it may be stated

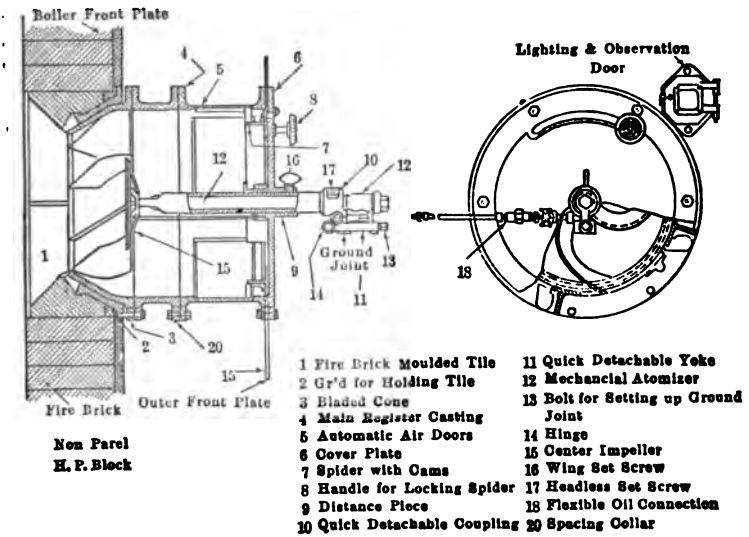


FIG. 258.—The Babcock & Wilcox Company's "Lodi" design of B. and W. mechanical oil burners, patented; double front construction for forced draft.

that the standard coal furnace may be adapted to oil burning without the necessity of changing the boiler setting. This refers

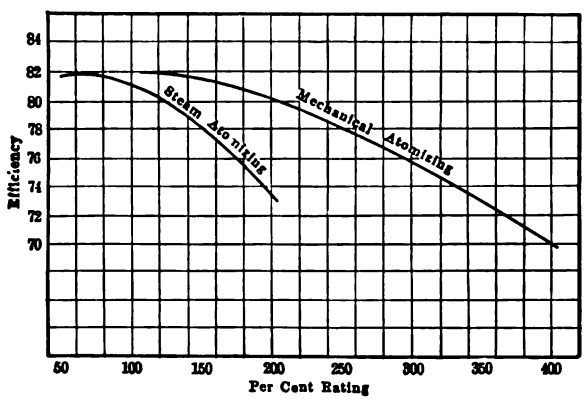


FIG. 259.—Taken from "Recent Changes in Oil Burning," by D. S. Jacobus and M. E. Lewis, published by the National Electric Light Association, New York, N. Y.

to stationary boilers—marine and locomotive boilers are run at much greater ratings per unit of heating surface, the furnaces are

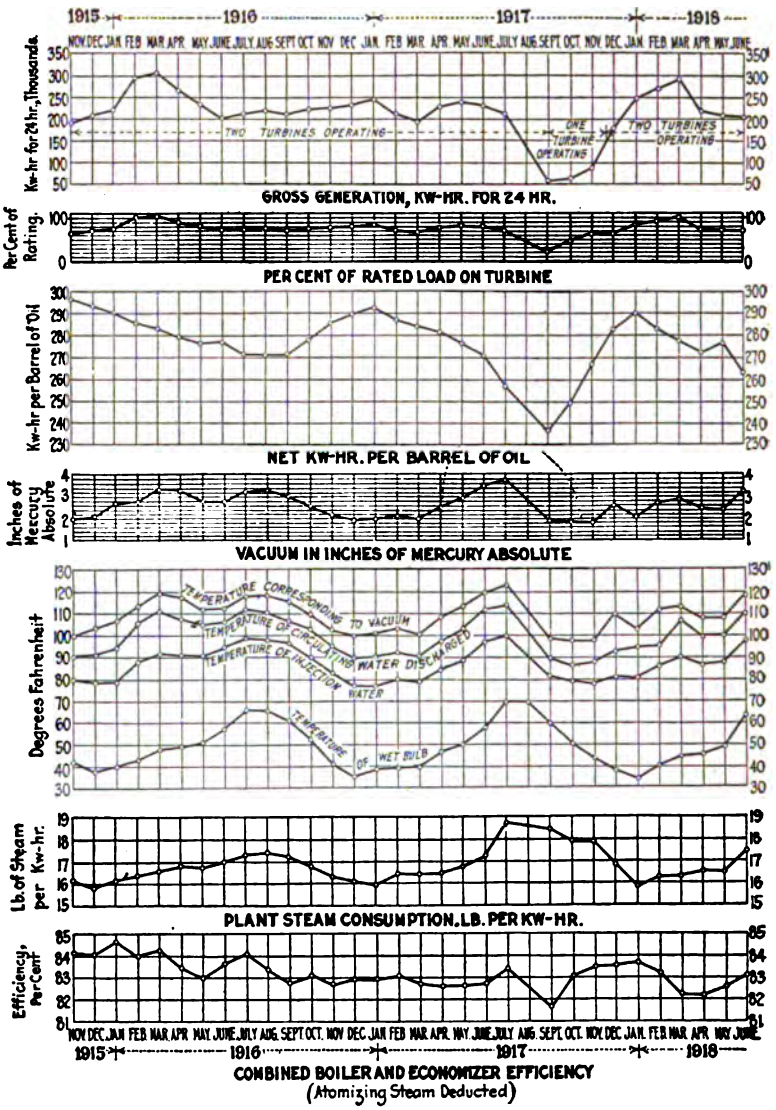


FIG. 260.—Operating characteristics of a power plant. (*From C. R. Weymouth's paper on "Economy of Certain Arizona Steam-Electric Power Plants," Am. Soc. Mech. Eng., June*, 1919, *Meeting.*)

usually small in comparison with stationary practice, and therefore furnace volume is one of the vital points to be considered.

As a result of personal observation, the author has obtained operating figures giving the relations between horsepower de-

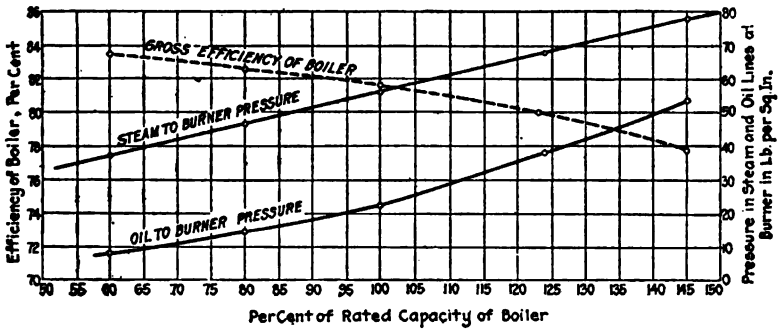


FIG. 261.—Pressures and efficiencies at various loads, steam atomizer oil burners. (*From C. R. Weymouth's paper, cit. supra.*)

veloped and furnace volume in cubic feet, in terms of cu. ft. per hp., for several types of boilers, as follows:

Type boiler	Type furnace	Cubic feet per horsepower	Per cent of rating
Babcock & Wilcox.....	Back shot	From 0.47 to 1.19	From 260 to 160
Heine.....	Front shot	1.54	140
Return Tubular.....	Front shot	1.01 to 1.67	
Scotch Marine.....	Front shot with extension furnace	1.74 to 2.33	

The above figures do not represent maximum capacity in each case.

CHIMNEYS

Because of the smaller volume of gases and the smaller draft required, much smaller chimneys are adequate for oil than for coal. A table of chimney ratings for oil fuel is given at the end of the Chapter. As a caution in using this table, note that the capacities given are maximum; and, in selecting a stack for any particular boiler, choose one from two to three times as large as the rated nominal boiler horsepower.

MARINE OIL BURNERS

The situation as regards marine burners is materially different from stationary burners, as the conditions are not comparable. In the first place, the use of steam for atomizing is undesirable because of the loss of fresh water, which would be a serious drain on the evaporators and fresh-water tanks; for this reason, burners of the mechanical-atomizer type are almost universally used on shipboard. Such burners atomize the oil by pressure alone, and some of the reasons the mechanical burner is not used for stationary work to a greater extent are: higher oil pressure and oil temperature required, greater first cost, greater draft required, less overload capacity without forced draft, and less flexibility. It is possible, in fact probable, that the mechanical atomizer will

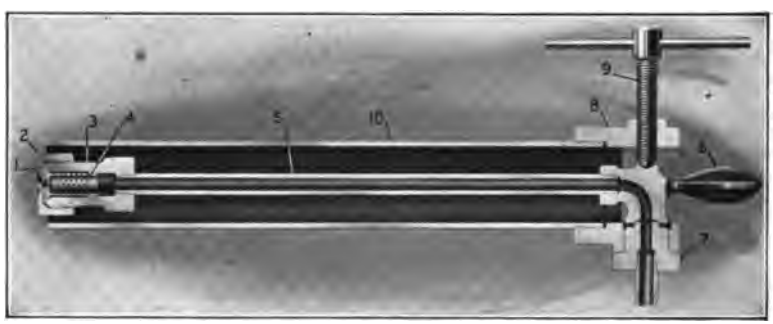


FIG. 262.—A sectional view of the Todd oil burner.

be adapted soon to stationary work when some of these drawbacks are overcome, since it possesses many inherent advantages over the steam burner.

There are several successful mechanical oil-burner systems for marine use in extensive use in the United States, and illustrations are given of several typical cases. There is considerable similarity in the general principle of all these systems, the two outstanding features of which are: the atomization of the oil is effected by centrifugal force imparted to the oil as it leaves the small orifice of the burner, the twirl being given by various devices inside the burner tip; and the air admission is individual to each burner and controlled by a so-called firing-front which, with the burner, forms a complete unit which is bolted into the front of the boiler, the furnace, therefore, being free of checkerwork such as used with steam atomizer burners.

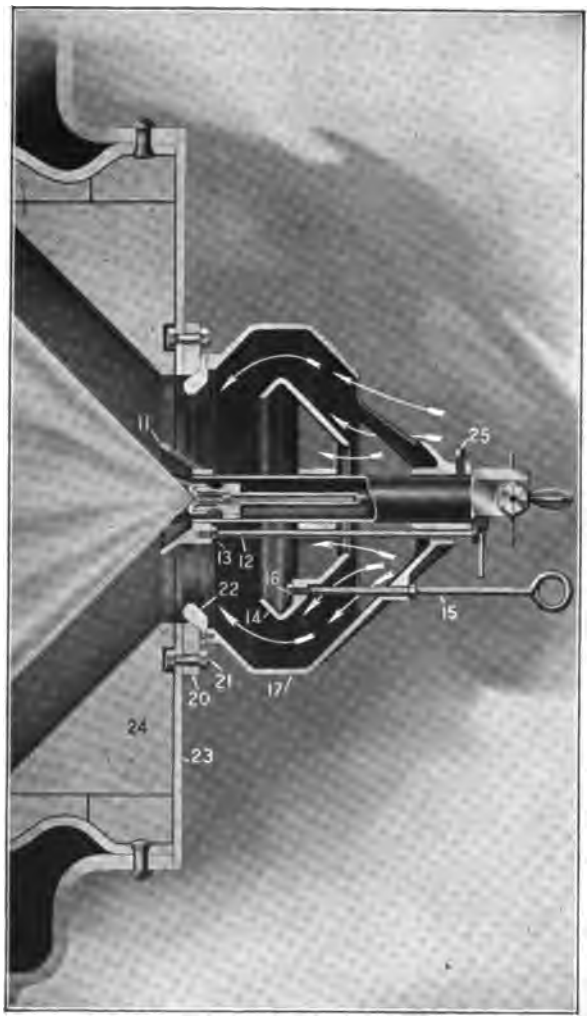


Fig. 263.—A sectional view of the Todd oil burner on a Scotch boiler.

Several of the marine system manufacturers supply pumping equipment and heaters, which are essentially the same as those

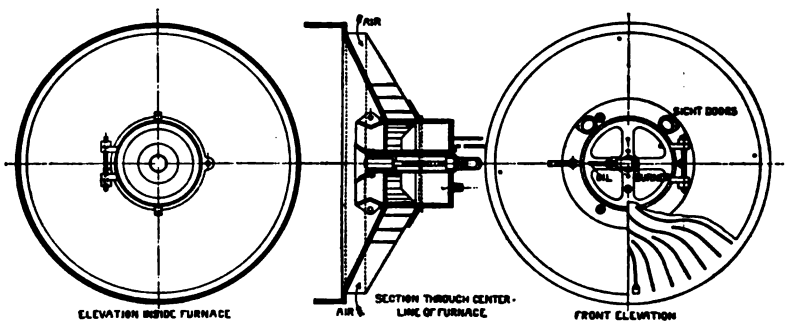


FIG. 264.—Firing fronts and burner, White system.

described for stationary work, but are adapted to higher oil pressures and temperatures, and usually are arranged to occupy

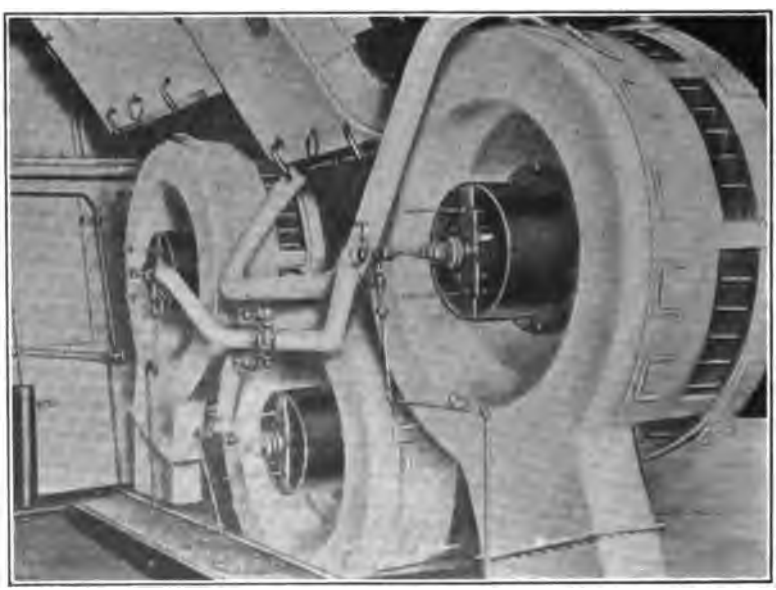


FIG. 265.—Stokehold arrangement, showing White combined positive and natural draft fronts in place over the furnace mouths.

a minimum of space; the oil heaters and strainers are often separate from the pumps, for mounting on a wall or bulkhead.

OPERATING ACCESSORIES

Soot Blowers.—There is a mistaken idea that there is no soot deposit on boiler tubes when burning oil. Under ideal conditions, such might be the case, but, actually, it is found necessary to dust the tubes, though not so often as with coal.

The dusting may be done with the ordinary hand steam lance, but much more thoroughly and economically by some form of mechanical soot blower, of which there are several on the market.

Draft Gages.—A draft gage, properly installed and used intelligently, is a great aid to efficient combustion; in fact, it is almost indispensable for proper check on operation.



FIG. 266.—The latest Coen firing front for oil-fired boilers. *A* is an adjustable damper which controls the air supply to the interior of the firing front; and *D* is a hinged part which allows it to be swung open; access to the furnace is available at any time without disconnecting or removing any parts.

The best form is the differential gage, with an individual gage on each boiler, connected so as to indicate the draft in the furnace.

CO_2 Instruments.—There is considerable diversity of opinion as to the merits of devices for indicating or recording the percentage of CO_2 in the flue gases. Such instruments require some skill in order to use them, considerable upkeep, and a thorough understanding of the meaning of the data obtained, in order to interpret them correctly.

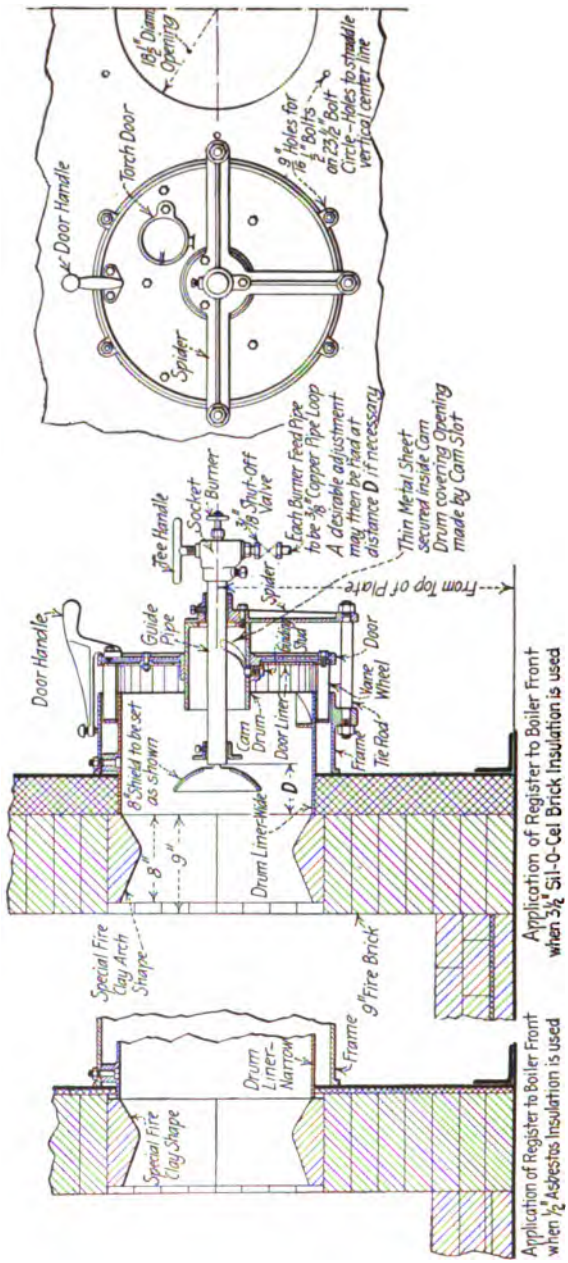


Fig. 267.—The Coen Company's mechanical oil-burning system.

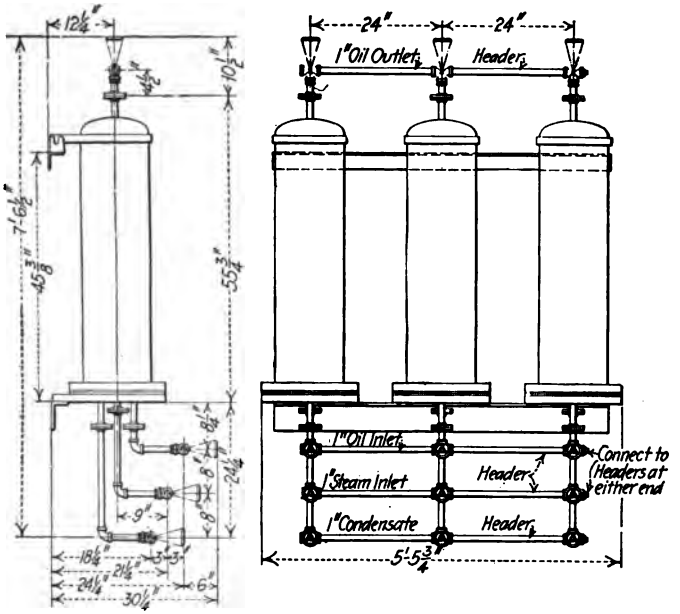


FIG. 268.—Three unit 12" × 50" cleanable heater piping arrangement; The Coen Company, San Francisco, Cal.

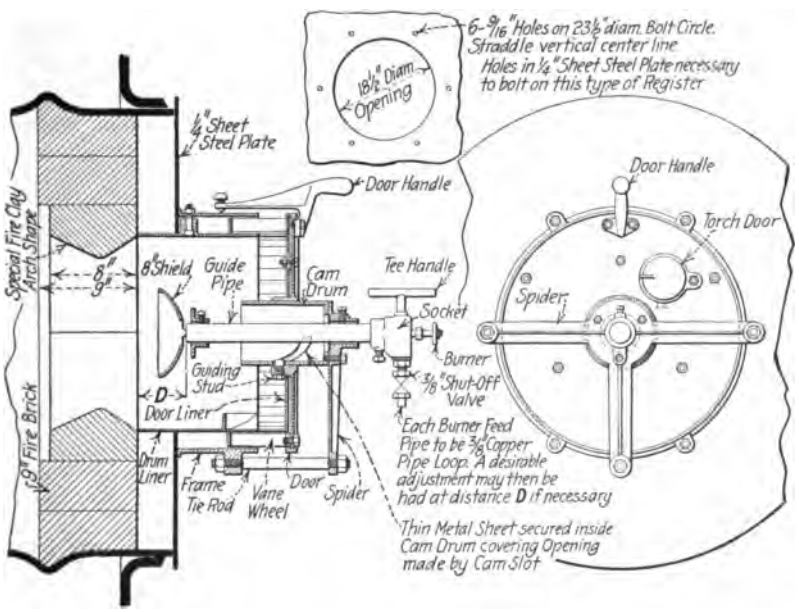


FIG. 269.—Type "R" register applied to internal furnace or flue; The Coen Company, San Francisco, Cal.

Undoubtedly, a knowledge of the percentage of CO_2 is useful when properly interpreted with relation to the load on the boilers, the condition of the brickwork setting and checkerwork, and the certainty that the gas sample has not been affected by air leakage due to improper sampling.

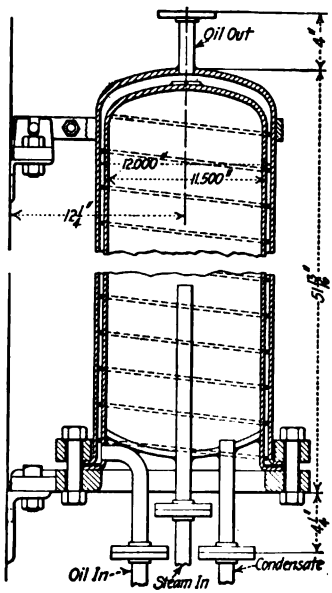


FIG. 270.—Coen cleanable fuel oil heater.

The author's opinion is that CO_2 readings are useful in the larger plants, which usually have an engineer or efficiency specialist who understands what factors must be considered; but for the average small plant he believes that the draft gage and stack thermometer are better guides to the operator.

Stack Thermometer.—A good stack thermometer, located at the proper place in the flue gas path, and with all air leakage through the breeching stopped—in other words, a true temperature reading of the flue gases—is a valuable aid, probably more so than with coal fires.

Flue gas temperature, when considered in relation to the same factors that were mentioned as affecting CO_2 determinations, is a good guide to excess air in the furnace.



FIG. 271.—Coen firing front for Scotch marine boilers. This swing-type firing front has been simplified somewhat from that shown in the preceding figure.

It is interesting to note that, up to a certain point within ordinary operating conditions, the temperature for a given load on a boiler will *rise* with excess air, though on first thought the reverse would be expected.

Other Instruments.—The use of oil lends itself naturally to keeping proper records of boiler performance; not only is it easier to keep records than with coal, but the more intelligent

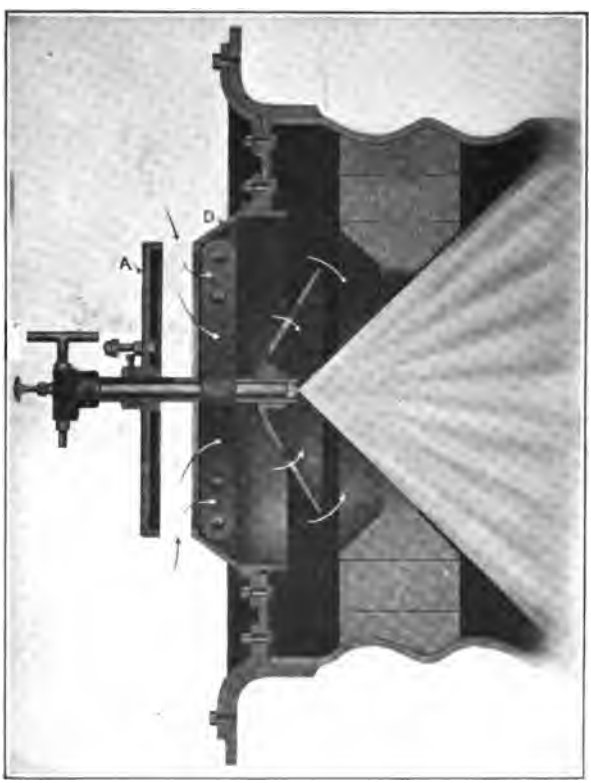


FIG. 272.—The Coen combination coal and oil firing front for natural draft Scotch boilers. The oil fire door *D* is interchangeable with the standard coal fire door on the Coen combination firing front for natural draft Scotch boilers, as shown above. The cast-iron combination ring *A* is made up of 4 sections and a throatpiece—easily removed when the grate bars are to be substituted for coal burning.

class of operators employed in oil-fired plants can be more easily trained to take necessary data.

In a properly conducted plant, the chief engineer should be

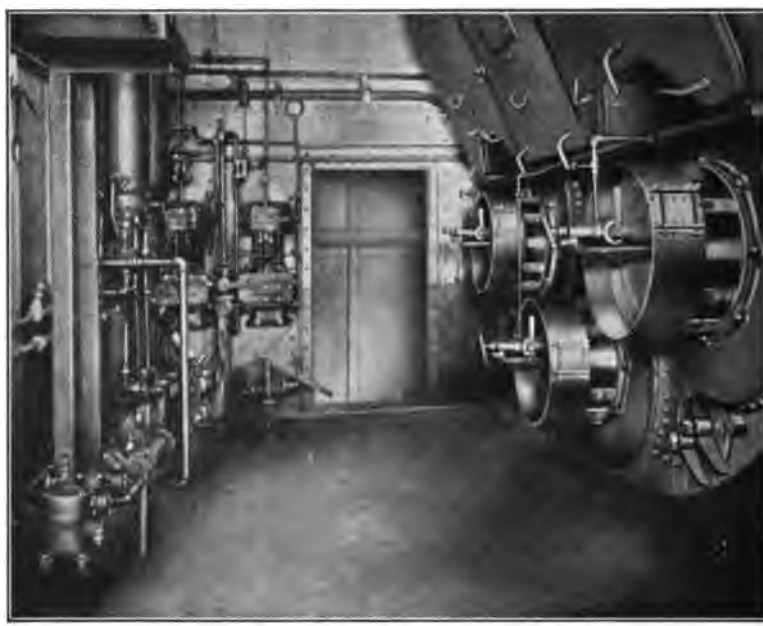


FIG. 273.—The Schutte & Koerting oil-burning installation.

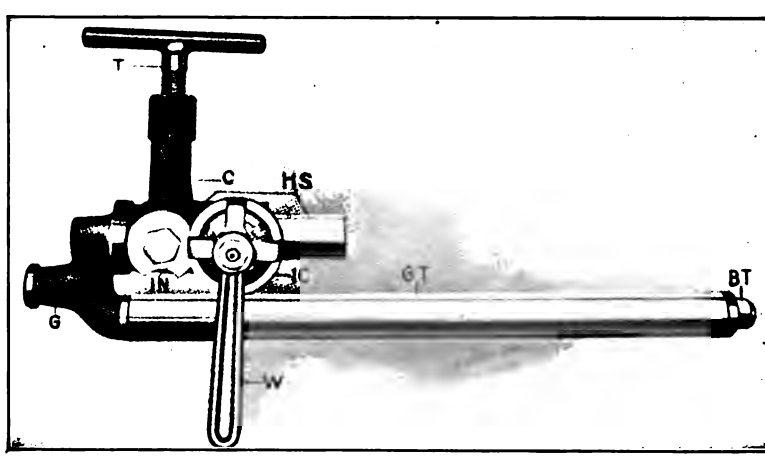


FIG. 274.—The Schutte & Koerting oil burner.

able to get daily readings of oil consumed, water evaporated, draft, stack temperature, and CO_2 analyses.

One such plant that the author visited had all these data for each 8-hr. shift in the fire room, and the owners stimulated competition by posting on a blackboard in the plant each fireman's daily record.

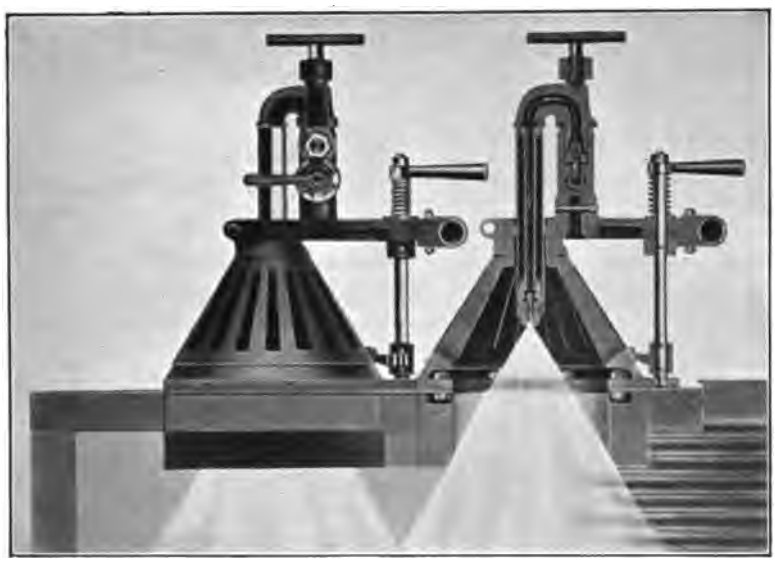


FIG. 275.—A section through a Koerting burner and air register installed on a United States torpedo boat destroyer.

TYPICAL FUEL OILS ON THE MARKET IN 1919, ALONG THE GULF AND ATLANTIC COASTS

Name	Vendor	Degrees Baumé at 60°F.	Flash-point, degrees Fahrenheit	B.t.u., pounds
Mexican crude	Natl. Petroleum Corp.	12.0	202	18,350
Topped Mexican crude		17.1	226	18,500
Navy fuel	Texas Co.	22½–24½	200	19,000
Bunker A	Texas Co.	19 –21	175	18,750
Bunker B	Texas Co.	18½–20½	175	18,750
Bunker C	Texas Co.	16 –17	150	18,500

Composition and Calorific Value of Various Oils[1]

Kind of Oil	Per cent carbon	Per cent hydrogen	Per cent sulphur	Per cent oxygen	Specific gravity	Degrees flash point	Per cent moisture	B.t.u. per pound	Authority
California, Coaling					0.927	134		17,117	Babcock & Wilcox Co.
California, Bakersfield					0.975	...		17,600	Wade
California, Bakersfield			1.30		0.992	...		18,257	Wade
California, Kern River					0.950	140		18,845	Babcock & Wilcox Co.
California, Los Angeles			2.56			...	...	18,328	Babcock & Wilcox Co.
California, Los Angeles					0.957	196		18,855	Babcock & Wilcox Co.
California, Los Angeles					0.977	...	0.40	18,280	Babcock & Wilcox Co.
California, Monte Christo					0.966	205		18,878	Babcock & Wilcox Co.
California, Whittier			0.98		0.944	...	1.06	18,507	Wade
California, Whittier			0.72		0.936	...	1.06	18,240	Wade
California	85.04	11.52	2.45	0.99*		...	1.40	17,871	Babcock & Wilcox Co.
California	81.52	11.51	0.55	6.92*		230	0.95	18,667	U. S. N. Liquid Fuel Board
California			0.87			...		18,533	Blasdale
California					0.891	257		18,655	Babcock & Wilcox Co.
California			2.45		0.973	...	1.50†	17,976	O'Neill
California			2.46		0.975	...	1.32	18,104	Shepherd
Texas, Beaumont	84.6	10.9	1.63	2.87	0.924	180		19,060	U. S. N. Liquid Fuel Board
Texas, Beaumont	83.3	12.4	0.50	3.83	0.926	216		19,481	U. S. N. Liquid Fuel Board
Texas, Beaumont	85.0	12.3	1.75	0.92*		...		19,060	Denton
Texas, Beaumont	86.1	12.3	1.60		0.942	...		20,152	Sparkes
Texas, Beaumont					0.903	222		19,349	Babcock & Wilcox Co.
Texas, Sabine					0.937	143		18,662	Babcock & Wilcox Co.
Texas	87.15	12.33	0.32		0.908	370		19,338	U. S. N.
Texas	87.29	12.32	0.43		0.910	375		19,659	U. S. N.
Ohio	83.4	14.7	0.6	1.3		...		19,580	
Pennsylvania	84.9	13.7		1.4	0.886	...		19,210	Booth
West Virginia	84.3	14.1		1.60	0.841	...		21,240	
Mexico					0.921	162		18,840	Babcock & Wilcox Co.
Russia, Baku	86.7	12.9			0.884	...		20,691	Booth
Russia, Novorossick	84.9	11.6		3.46		...		19,452	Booth
Russia, Caucasus	86.6	12.3		1.10	0.938	...		20,138	
Java	87.1	12.0		0.9	0.923	...		21,163	
Austria, Galicia	82.2	12.1	5.7		0.870	...		18,416	
Italy, Parma	84.0	13.4	1.8		0.786				
Borneo	85.7	11.0		3.31		...		19,240	Orde

[1] From Babcock & Wilcox Co's. "Steam."
* Includes nitrogen
† Includes silt.

RELATION BETWEEN SPECIFIC GRAVITY AND WEIGHT PER GALLON
Oils and Liquids Lighter than Water

Specific gravity	Degrees Baumé	Pounds per gallons	Specific gravity	Degrees Baumé	Pounds per gallon
1.000	10	8.336	0.775	51	6.462
0.993	11	8.277	0.771	52	6.428
0.986	12	8.220	0.767	53	6.394
0.979	13	8.161	0.763	54	6.358
0.972	14	8.104	0.759	55	6.324
0.966	15	8.051	0.755	56	6.290
0.959	16	7.997	0.751	57	6.258
0.953	17	7.944	0.747	58	6.212
0.947	18	7.891	0.743	59	6.195
0.940	19	7.837	0.739	60	6.163
0.954	20	7.785	0.736	61	6.133
0.928	21	7.736	0.732	62	6.101
0.922	22	7.687	0.728	63	6.070
0.916	23	7.638	0.724	64	6.038
0.911	24	7.590	0.721	65	6.006
0.905	25	7.541	0.717	66	5.975
0.899	26	7.493	0.713	67	5.946
0.893	27	7.444	0.710	68	5.916
0.887	28	7.395	0.706	69	5.886
0.881	29	7.347	0.703	70	5.856
0.876	30	7.298	0.699	71	5.827
0.870	31	7.254	0.696	72	5.797
0.865	32	7.210	0.692	73	5.771
0.860	33	7.166	0.689	74	5.743
0.854	34	7.122	0.686	75	5.715
0.849	35	7.079	0.682	76	5.688
0.844	36	7.038	0.679	77	5.659
0.840	37	6.998	0.676	78	5.632
0.835	38	6.696	0.672	79	5.603
0.830	39	6.918	0.669	80	5.576
0.825	40	6.878	0.666	81	5.548
0.820	41	6.839	0.662	82	5.517
0.816	42	6.804	0.658	83	5.487
0.811	43	6.760	0.655	84	5.457
0.806	44	6.721	0.651	85	5.427
0.802	45	6.683	0.648	86	5.402
0.797	46	6.644	0.645	87	5.574
0.793	47	6.608	0.642	88	5.353
0.788	48	6.571	0.639	89	5.316
0.784	49	6.534	0.636	90	5.304
0.779	50	6.498			

RULES AND REQUIREMENTS

—OF THE—

NATIONAL BOARD OF FIRE UNDERWRITERS

FOR THE

STORAGE AND USE OF FUEL OIL

AND FOR THE

Construction and Installation of

OIL BURNING EQUIPMENTS

AS RECOMMENDED BY THE

NATIONAL FIRE PROTECTION ASSOCIATION

EDITION OF 1913

CLASS A

LARGE SUPPLY OR STORAGE TANKS FOR OILS HAVING A FLASH-POINT ABOVE 150°F.

(Abel-Pensky Flash-point Tester.)

This flash-point corresponds closely to 160°F. (Tagliabue Open Cup Tester, which may be used for rough estimations of the flash-points.) These storage tanks are generally used for storage in oil fields, oil refineries or distributing stations and are in most cases installed above ground. The hazards of such systems of storage depend upon the distance from burnable property and upon the topography of the surrounding land.

1. Capacity and Location of Tanks.—(a) Tanks to be so located as to avoid undue exposure of adjacent burnable property. The distances specified in Table C are for plants or storage tanks located outside of fire limits.

TABLE C

MINIMUM DISTANCE OF TANKS

CAPACITY IN GALLONS	TO LINE OF ADJOINING PROPERTY WHICH MAY BE BUILT UPON FEET	TO ANY OTHER TANK, FEET
1,000	10	2
2,000	20	2
16,000	25	2
24,000	30	2
36,000	40	3
48,000	50	3
60,000	60	3
96,000	75	3
150,000	85	3
200,000	100	15
300,000	150	25
500,000	250	35
1,000,000	300	50
2,000,000	350	75
Unlimited	400	200

(b) Tanks to be located at lowest point available and so placed as to avoid possible danger from high water. When near a stream without tide, tanks to be located down-stream from the water front of any adjacent town. On tide water tanks to be located well away from shipping districts.

(*c*) When it is impossible to locate tanks as specified in Rule 1*b*, each tank to be surrounded with an embankment or dike not less than 4 ft. in height and having a capacity not less than 50 per cent greater than the tank to be protected.

(*d*) Embankments or dikes to be made of earth, reinforced concrete or brick. If made of earth, embankments to be firmly and completely built of earth from which stones, vegetable matter, etc., have been removed, and to have a crown of not less than three feet and a slope of at least 2 to 1 on both sides. If made of reinforced concrete or brick to be designed to provide protection equivalent to an earth embankment with a sufficient factor of safety to allow for the effect of fire on the concrete or brick facing.

(*e*) Embankments or dikes to be continuous, with no openings for piping or roadways. Piping to be laid well below the foundation of the embankments and, at points where it be necessary to pass over the embankment, properly built steps or concrete roadway to be provided.

2. Height of Tanks.—Vertical tanks must not exceed 30 ft. in height.

3. Material and Construction of Tanks.—(*a*) Tanks must be constructed of iron or steel plates of a gage depending upon the capacity as specified in the following table.

TABLE CI.—THICKNESS OF METAL FOR ABOVE GROUND TANKS

HORIZONTAL

MAXIMUM DIAMETER, FT.	MINIMUM THICKNESS HEADS, IN.	MINIMUM THICKNESS SHELL, IN.
Not over 5	5/16	9/64
5 to 8	1/4	5/16
8 to 11	3/8	1/4

VERTICAL

Capacity 5,000 gal. or less, diameter less than 40 ft.	
Bottom	No. 8 U. S. gage
Bottom ring	No. 8 U. S. gage
Other rings	No. 10 U. S. gage
Top	No. 12 U. S. gage
Capacity 10,000 gal. or less, diameter less than 40 ft.	
Bottom	No. 8 U. S. gage
Bottom ring	No. 7 U. S. gage
Other rings	No. 8 U. S. gage
Top	No. 12 U. S. gage

Other vertical tanks to be of material having a thickness of not less than indicated in the following. Figures in all columns excepting the first refer to U. S. standard gage.

Diameter in feet	Top	Top ring	2d ring from top	3d ring from top	4th ring from top	5th ring from top	6th ring from top	Bottom
80	10	7	7	3	0	3–0	5–0	10
75	10	7	7	4	1	2–0	4–0	10
70	10	7	7	4	1	2–0	4–0	10
65	10	7	7	5	1	0	3–0	10
60	10	7	7	5	2	0	2–0	10
55	10	7	7	6	3	1	2–0	10
50	10	7	7	7	4	1	0	10
45	10	7	7	7	5	3	1	10
40 & less	10	7	7	7	5	3	2	10

All riveted joints to have an efficiency of at least 60 per cent.

Tanks of greater capacity than given above shall be of material of sufficient thickness to safely hold the contents and proportionately heavier.

NOTE.—For materials to be used in smaller tanks, refer to Table CIII, giving weight of material for underground storage tanks.

(*b*) All joints of tanks must be riveted and soldered, riveted and caulked, brazed or welded, or made by some equally satisfactory process. Tanks must be tight and sufficiently strong to bear without injury the most severe strains to which they are liable to be subjected in transportation or use. Tanks shipped complete must be suitably reinforced to prevent injury to the joints.

(*c*) Tanks must be provided with a vent pipe terminating in a weather-proof hood containing a non-corrodible screen. In case the vent pipe is not permanently open, a suitable safety relief must be provided. When, in order to provide a means for relieving pressure, manhole covers are not provided with bolts or clamps, the openings must be protected by a non-corrodible wire mesh screen (not less than 20 by 20 meshes per square inch), which may be removable but must be normally securely held in place.

(*d*) Outside surfaces of tanks must be thoroughly protected against corrosion by a suitable rust-resisting paint.

4. Support for Tanks.—Tanks to be set upon a substantial foundation, and, when elevated above the ground level, supports are to be of non-combustible material, with exception of suitable wooden cushions. All above-ground tanks to be thoroughly grounded electrically.

5. Means for Extinguishing Fires in Tanks.—(*a*) Each tank to be equipped with an independent steam pipe for use in case of fire, the outlet of which is to be inside the tank, above the surface of the oil.

This pipe to be of ample capacity, but never smaller than ½ in.

(*b*) Steam which is to be supplied from conveniently located boilers to be controlled by valves outside the embankments surrounding the tanks.

NOTE.—Systems providing protection equivalent to the above may be used. Such systems generally embody the use of blanketing gas, and, when the source of supply is thoroughly reliable, may be satisfactorily employed where a supply of steam is not available.

6. Pumps.—Pumps used in connection with the supply and discharge of the tank shall be located outside of the reservoir walls and at such a point that they will be accessible at all times, even if the oil in the tank or reservoir should be on fire.

7. Pipe Connections.—All oil conveying pipes to be laid underground, but under no circumstances shall they break through the reservoir walls.

The above rule does not apply to pipes passing under the reservoir wall and laid well below the surface of the ground.

8. Controlling Valves.—(*a*) There shall be a gate valve located at the tank in each oil conveying pipe. In case two or more tanks are cross-connected there shall be a gate valve at each tank in each cross-connection.

(*b*) There shall be a gate valve in the discharge and suction pipes near the pump and a check valve in the discharge pipe, located underground.

9. Indicator.—There shall be a reliable indicator to show the level of the oil in the tank. Indicator to be of such a form that its derangement will not permit escape of oil.

10. Plans and Specifications.—A complete set of plans and specifications of proposed installation shall be submitted to the Inspection Department having jurisdiction before beginning construction.

CLASS B

INDIVIDUAL OIL-BURNING EQUIPMENTS FOR OTHER THAN HOUSEHOLD PURPOSES

Apparatus using oil for fuel, however safe-guarded, introduces a distinct increase in hazard which should be recognised.

Where used, the following rules should be rigidly observed.

All oil used for fuel purposes under these rules shall show a flash test of not less than 150°F. (Abel-Pensky Flash Point Tester.) This flash point corresponds closely to 160°F. (Tagliabue Open Cup Tester), which may be used for rough estimations of the flash point.

11. Capacity and Location of Tanks.—(*a*) In closely built up districts or within fire limits tanks to be located underground with tops of tanks not less than 3 ft. below the surface of the ground and below the level of the lowest pipe in the building to be supplied. Tanks may be permitted underneath a building if buried at least 3 ft. below the basement floor, which is to be of concrete not less than 6 in. thick. Tanks shall be set on a firm foundation and surrounded with soft earth or sand, well tamped into place. No air space shall be allowed immediately outside of tanks. Tank may have a test well, provided test well extends to near bottom of tank, and top end shall be hermetically sealed and locked except

when necessarily open. When tank is located underneath a building the test well shall extend at least 12 ft. above source of supply. The limit of storage permitted shall depend upon the location of tanks with respect to the building to be supplied and adjacent buildings, as given in the following table.

TABLE CII.—PERMISSIBLE AGGREGATE CAPACITY IF LOWER THAN ANY FLOOR, BASEMENT, CELLAR OR PIT IN ANY BUILDING WITHIN RADIUS SPECIFIED

CAPACITY	RADIUS, FT.
Unlimited	50
20,000 gal.	30
5,000 gal.	20
1,500 gal.	10
*500 gal.	Less than 10

* In this case tank to be entirely encased in 6 in. of concrete.

(*b*) When located underneath a building, no tank to exceed a capacity of 9,000 gal. and basement floors to be provided with ample means of support independent of any tank or concrete casing.

(*c*) Outside of closely built up districts or outside of fire limits, above-ground storage tanks may be permitted as specified in Rule 1, provided drainage away from burnable property in case of breakage of tanks is arranged for or suitable dikes built around the tanks. When dikes are employed the distances specified in Table 1 are to be taken as distances to nearest points of dikes.

When above-ground tanks are used, all piping must be arranged so that in case of breakage of piping the oil will not be drained from tanks. This requirement prohibits the use of gravity feed from storage tanks. Above-ground tanks of less than 1,000 gal. capacity without dikes may be permitted in case suitable housings for the protection of the tanks against injury are provided.

12. Material and Construction of Tanks.—(*a*) Tanks must be constructed of iron or steel plate of a gage depending upon the capacity as specified in the following tables.

TABLE CIII.—UNDERGROUND TANKS INSIDE OF SPECIFIED FIRE LIMITS, OR WITHIN 10 FT. OF A BUILDING WHEN OUTSIDE SUCH LIMITS

CAPACITY (GALLONS)	MINIMUM THICKNESS OF MATERIAL
1 to 560	14 U. S. gage
561 to 1,100	12 U. S. gage
1,101 to 4,000	7 U. S. gage
4,001 to 10,500	¼ in.
10,501 to 20,000	5/16 in.
20,001 to 30,000	⅜ in.

TABLE CIV.—UNDERGROUND TANKS OUTSIDE OF SPECIFIED FIRE LIMITS, PROVIDED THE TANKS ARE 10 FT. OR MORE FROM A BUILDING

CAPACITY (GALLONS)	MINIMUM THICKNESS OF MATERIAL
1 to 30	18 U. S. gage
31 to 350	16 U. S. gage
351 to 1,100	14 U. S. gage
1,101 to 4,000	7 U. S. gage
4,001 to 10,500	¼ in.
10,501 to 20,000	5/16 in.
20,001 to 30,000	⅜ in.

Tanks of greater capacity than 30,000 gal. must be made of proportionately heavier metal.

(*b*) All joints of tanks must be riveted and soldered, riveted and caulked, welded or brazed together, or made by some equally satisfactory process. To be tight and sufficiently strong, to bear without injury the most severe strains to which they are liable to be subjected in

Chimneys for Oil Fuel

Approximate Maximum Capacity; Actual Boiler Horsepower

Diameter, inches	Height in feet above boiler room floor line												Area, square feet
	50	60	70	80	90	100	110	120	130	140	150	160	
18	57	77	88	97	103	108	112	115	118	120	122	124	1.77
21	81	109	127	139	149	156	162	167	171	175	178	180	2.41
24	110	149	173	190	204	214	222	229	235	240	245	249	3.14
27	144	194	226	250	268	282	293	303	311	318	325	330	3.98
30	182	247	288	318	342	361	376	388	400	409	417	424	4.91
33	224	306	358	396	427	450	470	486	500	523	533	513	5.94
36	272	372	436	483	521	550	575	596	614	629	642	655	7.07
39	325	444	521	582	626	662	692	718	740	758	776	790	8.30
42	382	522	615	686	741	785	821	852	880	902	923	940	9.62
45	444	610	719	801	869	920	961	1,000	1,030	1,060	1,080	1,110	11.05
48	512	702	830	927	1,000	1,060	1,120	1,160	1,200	1,230	1,260	1,290	12.57
54	660	911	1,080	1,210	1,310	1,390	1,460	1,520	1,570	1,610	1,660	1,700	15.90
60	827	1,150	1,360	1,520	1,660	1,860	1,860	1,940	2,000	2,060	2,110	2,160	19.64
66	1,020	1,410	1,670	1,880	2,050	2,180	2,300	2,400	2,480	2,560	2,630	2,690	23.76
72	1,220	1,700	2,020	2,280	2,490	2,650	2,790	2,910	3,030	3,130	3,210	3,290	28.27
78	1,450	2,020	2,400	2,710	2,970	3,170	3,340	3,490	3,620	3,750	3,850	3,950	33.18
84	1,690	2,370	2,830	3,190	3,490	3,730	3,940	4,130	4,280	4,430	4,560	4,670	38.49
90	1,960	2,740	3,280	3,710	4,060	4,350	4,600	4,810	5,000	5,170	5,320	5,460	44.18
96	2,250	3,150	3,770	4,260	4,670	5,000	5,300	5,560	5,780	5,980	6,160	6,320	50.27
102	2,560	3,580	4,290	4,850	5,320	5,710	6,050	6,340	6,610	6,850	7,060	7,250	56.75
108	2,880	4,030	4,840	5,480	6,030	6,470	6,850	7,180	7,500	7,770	8,010	8,230	63.62
114	3,220	4,510	5,440	6,170	6,780	7,280	7,720	8,100	8,440	8,750	9,050	9,300	70.88
120	3,580	5,030	6,060	6,870	7,560	8,130	8,630	9,060	9,440	9,800	10,100	10,400	78.54
126	3,960	5,580	6,710	7,630	8,380	9,030	9,590	10,100	10,510	10,900	11,300	11,600	86.59
132	4,390	6,150	7,420	8,420	9,260	9,990	10,600	11,200	11,700	12,100	12,500	12,900	95.03
138	4,800	6,730	8,150	9,270	10,200	11,000	11,700	12,300	12,800	13,300	13,800	14,200	103.9
144	5,230	7,370	8,920	10,200	11,200	12,000	12,800	13,500	14,100	14,600	15,100	15,600	113.1
156	6,210	8,730	10,600	12,000	13,200	14,300	15,200	16,000	16,700	17,400	18,000	18,600	132.7
168	7,190	10,200	12,300	14,000	15,500	16,800	17,800	18,800	19,700	20,500	21,200	21,900	153.9
180	8,350	11,800	14,300	16,200	17,900	19,400	20,700	21,800	22,900	23,800	24,700	25,400	176.7

Note that table is for the overload capacity, maximum horsepower stacks will carry with oil.

LOCKETT AUTOMATIC FUEL OIL PUMPING EQUIPMENT FOR HEAVY OILS AND RESIDUUM

Black Face Type Indicates Standard Outfits

Style	Size	Size of pumps	Number of pumps	Boiler, hp.	Shipping weight, pounds, approx.	Type of heater	Heating surface, square feet	Size and type of strainer	Type of governor	Steam	Exhaust	Suction	Discharge	Floor space, inches	Height, inches
1	A-1	3×2×3	1	200	225	None		1¼ Kieley	Kieley	⅜	½	1¼	1	9×40	41
1	A-2	3½×2¼×4	1	500	300	None		1½ Lockett	Kieley	⅜	¾	1½	1	9×48	44
1	A-3	4½×2¾×4	1	1,000	325	None		2 Lockett	Kieley	⅜	¾	2	1¼	15×54	48
2	B-1	3×2×3	2	200	375	None		1¼ Kieley	Witt	⅜	½	1¼	1	30×51	38
2	B-2	3½×2¼×4	2	500	575	None		1½ Lockett	Witt	⅜	¾	1½	1	30×51	38
2	B-3	4½×2¾×4	2	1,000	905	None		2 Lockett	Witt	½	¾	2	1¼	36×61	41
2	B-4	5¼×3½×5	2	2,500	1,490	None		2½ Lockett	Witt	¾	1¼	2½	1¼	60×70	54
2	B-5	6×4×6	2	4,000	1,890	None		3 Lockett	Witt	¾	1¼	3	2	64×98	54
3	C-1	3×2×3	2	200	1,000	Porc. (Hor)	14.8	1¼ Kieley	Witt	½	½	1¼	1	30×51	54
3	C-2	3½×2¾×4	2	500	1,098	Porc. (Hor)	14.8	1½ Lockett	Witt	½	¾	1½	1	30×51	54
3	C-3	4½×2¾×4	2	1,000	2,098	Porc. (Hor)	24.8	2 Lockett	Witt	¾	¾	2	1¼	36×61	63
3	C-4	5¼×3½×5	2	2,500	3,388	Porc. (Hor)	49.6	2½ Lockett	Witt	¾	1¼	2½	1¼	60×70	54
3	C-5	6×4×6	2	4,000	5,298	Porc. (Ver.)	140.0	3 Lockett	Witt	1	1¼	3	2	46×132	96
3	C-6	7½×5×6	2	6,000	6,586	Porc. (Ver.)	174.0	4 Lockett	Witt	1¼	2	4	2	54×138	109
3	C-7	9×5¼×10	2	10,000	8,322	Porc. (Ver.)	210.0	4 Lockett	Witt	1½	2½	4	2½	60×158	123

practice. The shells of tanks to be properly reinforced where connections are made and all connections should as far as practicable be made through the upper side of tanks above oil level.

(*c*) Tanks shall be thoroughly coated on the outside with tar, asphaltum, or other suitable rust-resisting material.

NOTE.—The protection required for tanks will depend upon the condition of the soil in which they are installed. When the soil is impregnated with corrosive materials tanks should be made of heavier metal, in addition to being protected as specified above.

12. Fill and Vent Pipes.—(*a*) Each underground storage tank having a capacity of over 1,000 gal. to be provided with at least a 1 in. vent pipe extending from the top of the tank to a point outside of building. Vent pipe to terminate at a point at least 12 ft. above the level of the top of the highest tank car or other reservoir from which the storage tank may be filled. Terminal to be provided with a hood or goose neck protected by a non-corrodible screen and to be located remote from fire escapes and never nearer than 3 ft., measured horizontally and vertically, from any window or other opening. Vent pipes from two or more tanks may be connected to one upright, provided the connection is made at a point at least one foot above level of source of supply.

(*b*) Tanks having a capacity of less than 1,000 gal. may be provided with combined fill and vent pipes so arranged that the fill pipe cannot be opened without opening the vent pipe, these pipes to terminate in a metal box or casting provided with a lock.

(*c*) Fill pipes for tanks which are installed with permanently open vent pipes must be provided with metal covers or boxes which are to be kept locked except during filling operations.

(*d*) Fill and vent pipes for tanks located under buildings are to be run underneath the concrete floor to outside of building.

14. Indicator.—Some device for indicating the level of the oil is desirable. Where used, such attachment shall be connected through substantial fittings so as to minimize exposure of the oil, and devices the breakage of which will allow the escape of oil, must not be used.

15. Filters.—Suitable filters or strainers for the oil should be installed and preferably be located in supply line before reaching pump. Filter to be arranged so as to be readily accessible for cleaning.

BOILER EFFICIENCY FOR EXCESS AIR SUPPLY

Excess air supply, per cent.	10	50	75	100	150	200
Assumed temperature of escaping gases, deg. F.	400	450	475	490	Over 500	Over 500
Corresponding ideal efficiency of boiler, per cent.	84.2	80.27	77.66	65.22	Under 70.94	Under 67.09
Possible saving in fuel due to reduction of air supply to 10 per cent excess, expressed as per cent of oil actually burned under assumed conditions.	0	4.67	7.78	10.68	Over 15.76	Over 20.32

PARTIAL LIST OF OIL-DISTRIBUTING STATIONS IN THE UNITED STATES
(Including Some Now Building)

Place	Oil company	Storage capacity, barrels of 42 gal.
Aberdeen, Wash.	Standard Oil Co. of California	34,000
Alameda Point, Cal.	Associated Oil Co.	37,500
Aransas Pass, Tex.	The Texas Co.	55,000
Astoria, Ore.	Standard Oil Co. of California.	10,000
Avon (Suisun Bay), Cal.	Associated Oil Co.	1,000,000
Baltimore, Md.	Interocean Oil Co.	220,000
Baltimore, Md.	Standard Oil Co. of N. Jersey	50,000
Baltimore, Md.	The Texas Co.	55,000
Baton Rouge, La.	Standard Oil Co. of Louisiana	
Bayonne, N. J. (New York Harbor).	Standard Oil Co. of N. Jersey	300,000
Bayonne, N. J.	The Texas Co.	276,000
Bellingham, Wash.	Standard Oil Co. of California	8,500
Boston, Mass.	Mexican Petroleum Co.	200,000
Boston, Mass.	Standard Oil Co. of New York	50,000
Boston, Mass.	United States Navy	50,000
Carteret, N. J. (Near New York).	Interocean Oil Co.	100,000
Chester, Pa.	Interocean Oil Co.	120,000
Charleston, S. C.	Standard Oil Co. of N. Jersey	15,000
Charleston, S. C.	The Texas Co.	104,000
Charleston, S. C.	United States Navy	35,000
Cristobal, Panama.	The Texas Co.	110,000
El Segundo, Cal.	Standard Oil Co. of California	100,000
Eureka, Cal.	Standard Oil Co. of California	35,000
Galveston, Tex.	The Texas Co.	110,000
Gaviota, Cal. (Santa Barbara Channel).	Associated Oil Co.	120,000
Guantanamo Bay, Cuba.	United States Navy	212,000
Honolulu, Hawaiian Islands.	Associated Oil Co.	102,000
Honolulu, Hawaiian Islands.	Standard Oil Co. of California	100,000
Jacksonville, Fla.	Standard Oil Co. of Kentucky	50,000
Jacksonville, Fla.	The Texas Co.	55,000
Ketchikan, Alaska.	Standard Oil Co. of California	38,000
Key West, Fla.	Standard Oil Co. of Kentucky	50,000
Key West, Fla.	U. S. Navy	35,000
Linnton, Oregon (9 miles from Portland).	Associated Oil Co.	173,000
Marcus Hook, Del.	Sun Oil Co.	500,000
Mare Island, Cal.	United States Navy	100,000
Melville Station, Rhode Island.	United States Navy	85,000
Mobile, Ala.	The Texas Co.	25,000
Monterey, Cal.	Associated Oil Co.	340,000
Morgan City, La.	The Texas Co.	55,000
New Orleans, La.	Mexican Petroleum Co.	400,000
New Orleans, La.	The Texas Co.	124,000
New York, N. Y.	Mexican Petroleum Co.	500,000
New York, N. Y.	Standard Oil Co. of New York	100,000
Norfolk, Va.	The Texas Co.	138,000
Norfolk, Va.	United States Navy	185,000
Oakland, Cal.	Standard Oil Co. of California	10,000
Panama.	Mexican Petroleum Co.	100,000
Pearl Harbor, Hawaii.	United States Navy	235,000
Philadelphia, Pa.	The Texas Co.	334,000
Point Breeze, Pa. (Philadelphia).	Atlantic Refining Co.	500,000

PARTIAL LIST OF OIL-DISTRIBUTING STATIONS IN THE UNITED STATES
(*Continued*)

Place	Oil company	Storage capacity, barrels of 42 gal.
Point Wells, Wash. (13 miles from Seattle)	Standard Oil Co. of California	200,000
Port Arthur, Tex	The Texas Co.	Practically unlimited
Port Chalmette, La	Standard Oil Co. of Louisiana	
Port Costa, Cal. (Carquines Strait)	Associated Oil Co.	480,000
Portland, Maine	Mexican Petroleum Co.	200,000
Portland, Maine	Standard Oil Co. of New York	30,000
Portland, Ore	Standard Oil Co. of California	85,000
Port Townsend, Wash	Standard Oil Co. of California	27,000
Providence, R. I	Mexican Petroleum Co.	100,000
Providence, R. I	Standard Oil Co. of New York	10,000
Providence, R. I	The Texas Co.	253,000
Puget Sound, Wash	United States Navy	100,000
Richmond, Cal	Standard Oil Co. of California	200,000
Sacramento, Cal	Associated Oil Co.	5,100
Sabine Pass, Tex	Sun Oil Co.	250,000
San Diego, Cal	Standard Oil Co. of California	34,000
San Diego, Cal	United States Navy	100,000
San Francisco, Cal	Associated Oil Co	97,800
San Francisco, Cal	Standard Oil Co. of California	15,000
San Pedro (East), Cal	Standard Oil Co. of California	35,000
Seattle, Wash	Standard Oil Co. of California	90,000
Stockton, Cal	Associated Oil Co.	5,200
Tacoma, Wash	Standard Oil Co. of California	34,000
Tampa, Fla	Standard Oil Co. of Kentucky	70,000

Fuel oil is obtainable from distributing stations of the Imperial Oil Co., Ltd., at—

Fort William, Ont.
Halifax, N. S.
Montreal, Que.
Prince Rupert, B. C.
Quebec, Que.
Sarnia, Ont.
Toronto, Ont.
Vancouver, B. C.
Victoria, B. C.

Oil can also be obtained at many European and Asiatic ports and also in South America, but efforts to secure a list of these stations have met with so little success, and the list is so incomplete, that it has been concluded to omit it altogether.

A Select Bibliography of Liquid Fuels

ANDROS, S. O., "Fuel Oil in Industry," **1920.**
BEST, W. N., "Science of Burning Liquid Fuel," **1913.**
BOOTH, W. H., "Liquid Fuel and Its Apparatus," **1911.**
BRAME, J. S. S., "Fuel: Solid, Liquid and Gaseous," **1914.**

BUTLER, EDWARD, "Oil Fuel," **1914.**
DUNN, F. B., "Industrial Uses of Fuel Oil," **1916.**
LEWES, V. B., "Liquid and Gaseous Fuels and the Part They Play in Modern Power Production," **1913.**
MOORE, HAROLD, "Liquid Fuels for Internal Combustion Engines," **1918.**
NORTH, S. H., "Oil Fuel: Its Supply, Composition and Application," **1911.**
PEABODY, E. H., "Oil Fuel," **1915.**
POOLE, HERMAN, "The Calorific Power of Fuels," **1918.**
SIBLEY, R., and DELANY, C. H., "Elements of Fuel Oil and Steam Engineering," **1918.**
STROHM, R. T., "Oil Fuel for Steam Boilers," **1914.**

CHAPTER XII

COLLOIDAL FUEL

By

Lindell T. Bates*

Colloidal fuel is a composite—a liquid, a mobile paste or gel—in which pulverized carbonaceous substance and liquid hydrocarbon complex are so combined and treated as to form an adequately stable atomizable fuel. The use is primarily as fuel for burning purposes. The products is designated by the term "colloidal fuel" and the process is called "colloidalizing." The word "colloidal" in these instances is not used in a strictly technical sense, although much of the fuel is in the colloidal state. It is employed conveniently to describe the product and process, owing especially to certain of the fuel's important colloid-like characteristics.

In view of the well-known economic and operative advantages of atomizable fuel over solid fuel, and the high value and comparative scarcity in many places of certain refinable oils, there has long been felt the desirability of evolving a process for combining for purposes of economy the cheaper or more plentiful sources of carbon with those hydrocarbons in such a fashion as to admit of atomization and simultaneous combustion of the components. The cheaper and more plentiful sources of carbon are generally solids, such as coal and lignites, or tars or pitches. Attempts have been made in the past to make a liquid fuel of pulverized coal with oil and of tar with oil; but, as oil ordinarily does not dissolve coal or tar, comparatively rapid and uncontrolled separation, settling out or sedimentation of some of the components, or complication or cost of the combination-treatment developed, has heretofore discouraged industrial use of the product.

Modern chemistry distinguishes three states in the dispersion of combined substances, whether the composite and components

* Mt. Lebanon, N. Y.; during the World War, Secretary Submarine Defense Association, New York, N. Y.

be in the liquid, gaseous or solid form. These states are the solution, colloid, and suspension. They merge into one another but have in several respects distinctive characteristics. The boundaries between the so-called "molecular" solutions, the colloids, and the so-called "coarse" or "mechanical" suspensions are arbitrary, but today chemists are agreed in their delimitation. True solutions are deemed to exist when the particles or droplets of the disperse phase in the dispersion medium are of a dimension less than $1\mu\mu$, that is, have a diameter less than 0.000,0001 cm. Colloids are those combinations in which the dispersed particles or droplets are between 0.1μ and $1\mu\mu$ in diameter, *i.e.*, are less than 0.000,01 but greater than 0.000,0001 cm. in size. In suspensions the diameter or size of these particles or droplets is larger than 0.000,01 cm., or $0.1\mu\mu$. There are a number of practical distinctions between the colloid and suspension states. Particles of 0.001 cm. in size in a suspension just show Brownian movement, while the particles in a colloid display rapid movement of this category. Colloids can be filtered through the finest filter-paper without appreciable loss of particles, whereas the particles of a suspension are retained. The best microscopes, magnifying 2,250 times, just make visible particles 0.15μ in size Larger particles may be measured under this instrument. But particles of less size, which means that the particles are within colloidal limits, are detectable only with the ultramicroscope.

It is characteristic of solutions, whether the molecules of the particles or droplets actually combine or do not combine with those of the medium, that the dispersed particles or droplets do not settle to the bottom, float to the top or separate under normal conditions. The same is true with respect to colloids, provided the particles or droplets are sufficiently within the upper limit of the colloidal state. The requisite margin within the upper limit depends upon the real and apparent specific gravity of the dispersed substance, the characteristics of the medium, and other factors. Colloids enjoy absolute or relative stability as a natural attribute of their state. Of course, solutions and normally stable colloids may be so treated as to precipitate, in some cases, the dispersed particles and droplets. Weight has a notable effect on suspension, producing the deposition of the dispersed particles as small as one-tenth of the length of a light wave, $50\mu\mu$. Hydrosols in which the particles are less than $20\mu\mu$ in size remain quite clear and do not settle at all. Par-

ticles of 10$\mu\mu$ diameter and 3.0 sp. gr. settle in water a distance of only 1 mm. a month.

In order for a fuel to be atomizable and for its components to be simultaneously combustible, it is necessary that the fuel be mobile and that it possess adequate stability to enable it to pass through the pipes, preheater and other apparatus parts without the components congesting therein to such an amount as to prevent the fuel's passage. The degree and duration of the adequate stability desired vary according to the contemplated handling and use of the fuel. For some purposes a few minutes of stability are alone required. This is the case where the fuel is burned directly after preparation. For other purposes, as where storage is intended, stability not merely for some days but even for months may be desired. To give the utility character required, it is essential to prevent or delay settling to the bottom of the medium or floating to the top on the part of the particles or droplets for a reasonable length of time, and, to a reasonable extent, depending in duration and degree upon several variable factors, including the length of proposed fuel storage after manufacture and the character of the burning, conveying and atomizing systems. In referring herein to "stability," such adequate stability is meant. Regulation and control, within reasonable limits, of the movement of the dispersed substance, to give the fuel a stability of the required degree and duration, are sufficient for the practical purposes of fuel utilization. In order to understand how such power over stability may be obtained and exercised, it is appropriate to describe the laws governing the movement of dispersed particles and droplets in a liquid medium.

An investigation of stability is best approached from a consideration of Stokes' law for the terminal velocity of fall of a spherical body in a liquid. According to this law, the velocity per second under a constant force such as gravity is derived from the following equation:

$$V = \frac{2r^2(s - s')g}{9\eta}$$

In this expression g is the constant of acceleration per unit mass, that is, gravity; r is the radius of the sphere; s is the specific gravity of the sphere and s' that of the liquid; and η is the absolute viscosity coefficient of the liquid. It is obvious, as stated by Hatschek, that the difference (s–s') may be positive, zero or

negative; that is, the particle may sink, remain stationary or rise as its specific gravity is greater, equal to, or smaller than that of the liquid. The velocity, in whichever direction, is inversely proportional to the viscosity of the liquid and is proportional to the square of the radius ("An Introduction to the Physics and Chemistry of Colloids," **1916**, pp. 23 and 24).

One may calculate the theoretical rate of settling of pulverized coal in oil, for example, according to this formula, if given the figures corresponding to the several terms. In the case of a pulverized anthracite coal which is combined with a heavy crude oil, heated several times to between 200 and 300°C. to remove most of its volatile components, the following figures are obtained at 20°C.:

g = 981 cm. (32.181′); s = 1.467; s' = .9; and
η = 6.7 to 7.0.

The radius of the coal particles may be taken with sufficient exactness as one-quarter of the reciprocal of the mesh number of the screen through which the coal passes on pulverization. This assumption is based upon the hypothesis that the interval between the wires of the screen equals the diameter of the wire. The diameter or size of the maximum particles which pass a 50-mesh screen is taken as 0.0254 cm. The size of the largest particles passing 100-, 200- and 400-mesh screens is computed as about 0.0127 cm., 0.00634 cm. and 0.00316 cm., respectively. Particles of these sizes are greatly above the colloidal size, whose upper limit is 0.000,01 cm. Coal particles pulverized to pass through a 50-mesh screen would settle in view of these figures 244.189 cm. (96.137 in.) a day. To the meshes 100, 200 and 400 correspond, respectively, the distances of fall of 6.047 cm. (24.034 in.), 15.262 cm. (6.008 in.) and 3.815 cm. (1.502 in.) a day.

While the theoretical rate of settling is most rapid, the actual rate is less than the theoretical. This is due to the fact that in such a composite Stokes' law does not have undisturbed play. The coal particles are not spherical; there are platelets and spicules. Some may be of a size such as will form with the oil a solution or a naturally stable colloid; some may also be below the weight and size necessary to overcome the surface tension, the plastic inner friction of viscosity of the oil. The presence of many particles in the medium may also delay sedimentation

initially; but when flocculation occurs, the sedimentation may be accelerated.

Although the actual natural rate of settling of particles and droplets of sizes corresponding to the screens mentioned in a medium of liquid hydrocarbon is less than the theoretical, it is too rapid to allow the composite to be used as fuel save in very exceptional cases. In ordinary combinations, for example, of pulverized coal and oil, the particles of coal being heavier than the oil have settled out in the pipes or preheater and have choked these conduits or they have settled to the bottom of the storage tank, somewhat in the fashion of sand in water, which has defeated the purpose of simultaneous combustion of the components of the fuel. There has been a similar experience in the case of tar combined with oil. Resort to constant stirring has been proposed and tried, but even in the case of a short pipe system congestion in the pipes has occurred. No product adequately stable of itself has heretofore been supplied to industry.

In regard to suspending particles in liquids there exists some prior experience in connection chiefly with colloids. It is known in chemistry that particles in a liquid are normally stable if sufficiently within colloidal limits and that they may be precipitated by certain substances, such as electrolytes. "Protective colloids" possess the property of preventing such precipitation, unless a larger amount of precipitating agent is used. Of protective colloids there are a number enumerated in standard chemical textbooks. The list includes such substances as gelatine, glues, casein, gum arabic, sodium oleate, dextrin, silicic acid, and aged stannic acid. Chemists are not agreed whether the action of a protective colloid is to surround the particles with a film, to adsorb with them, or to introduce electrical factors, with resultant effects on surface tension, apparent specific gravity and other characteristics affecting stability. Probably the stabilizing effect is produced by a combination of these and other phenomena. It is also familiar that protective colloids delay the settling or floating tendency of particles and droplets, irrespective of the introduction of a precipitating agent, and that the protective action of some few colloids extends to a certain degree to suspensions. Colloids of charcoal and lampblack are known. It is reported that coal may be made into a stable combustible colloid with oil, or brought into a state closely approximating the colloidal

condition, when it is reduced therein under high-pressure or high-speed disc grinding and lengthy trituration, whose duration may be reduced somewhat by adding a colloid to the mixture which assists the endeavor to decompose the coal to molecules. So also it is understood that the settling of up to 3 per cent of graphite, whose particles are above colloidal size, is delayed, sufficiently for lubricating purposes, when castor oil is used to create a film around the graphite particles. But suspension of a high percentage of particles above colloidal size is quite without precedent. With regard to the production of a stable composite by peptizing carbonaceous substance in liquid hydrocarbon, there is apparently no prior art, save Acheson's experience with tannin on graphite for lubricants and even in this case there is uncertainty whether the tannin acts as a protective colloid or as a peptizing agent.

Turning to the state of the art with respect to stabilizing a composite of two or more immiscible or partially miscible liquid hydrocarbons for fuel purposes, there is little history. It is well known that many liquid hydrocarbons are miscible with others. But there are certain important combustible liquid hydrocarbons that until now have proved refractory to combining—for instance, fuel oil and tar have been to date immiscible or partially miscible only. Emulsions of immiscible liquid hydrocarbons have been made suitable for creosoting and disinfecting, but no such emulsions, much less suspensions, involving immiscible liquid hydrocarbons for fuel purposes are recorded.

Early in the Great War the fuel situation attracted attention. The powerful units of the navies of the allied powers have for some years been dependent chiefly upon oil fuel for their motive power.

In view of the critical situation, the British Admiralty sent to Lindon Bates drawings of the boiler installations of the Queen Elizabeth class of superdreadnaughts and asked whether such vessels could advantageously burn pulverized coal. A conference was held with the leading American companies interested in pulverized coal, with the result that several systems were tried out on the naval vessel U.S.S. "Gem." Pulverized coal had heretofore been used on land but marine experience had been exceedingly limited. As the naval vessel was equipped with the highest class of Normand destroyer boilers, the demonstrations were authoritative. It was amply shown that pulverized coal could be burned on shipboard and steam duly maintained.

However, inasmuch as coal when pulverized occupies about twice the volume of oil for equal heat units, such use would very materially cut down the steaming radius. For strategic reasons, therefore, the use of pulverized coal on battleships of the Grand Fleet could not be recommended.

Recognizing in advance the probability that this would be the result experienced, Lindon Bates early decided to resume the old efforts to combine coal and oil into a liquid fuel for the purpose of saving oil without decreasing steaming capacity and radius. At his instance, and through the courtesy of George Eastman and Dr. C. E. K. Mees, the facilities of the Kodak Research Laboratory at Rochester were made available, and expert chemists, particularly Dr. S. E. Sheppard, J. G. Capstaff and L. Ebelin, were delegated to investigate the laboratory aspects of the subject. As a result of many months careful study, it was verified that a satisfactory colloidal fuel composite could be made. After numerous laboratory tests at Rochester, a supply of the composite was made elsewhere for marine service tests under the Submarine Defense Association's auspices. These took place from April to July, 1918, on the U.S.S. "Gem" and were successful. Demonstrations were made before officials of the United States and allied goverments and navies, and numerous favorable reports were made—to the British Admiralty, for example, and to other bodies by their specially delegated officers.

When the Armistice came suddenly in November, 1918, the Naval crisis passed. Attention was directed, therefore, from the marine emergency need to the peace uses for colloidal fuel. Mr. Bates arranged to install a temporary equipment at the Sone & Fleming Refinery of the Standard Oil Co. of New York, at Newtown Creek, Brooklyn. The purpose was to produce sufficient fuel to test its utility in land service, to supply collodial fuel for extensive tests, and to observe the effects of variations in components of the fuel. Early in 1919 the installation was completed and from March to July, 1919, various grades of collodial fuel were made and boiler tests conducted. These trials confirmed the efficiency of the fuel.

One may now describe in a general way the scientific bases of the product and process of colloidal fuel. Reduction of the carbonaceous substances to such a size that the particles enter into a molecular, colloidal or practically colloidal state with the liquid

hydrocarbon is known to promote natural stability. But the manner of so doing is most arduous and not suited to industrial needs. The question, however, of diffusion or scattering of the particles through the liquid is also of importance with reference to stability. It has been found, as the result of extensive tests, that, if the components are properly mixed and treated, it is not necessary to reduce the particles so finely. The scientific reason is that the size and weight of the particles are not the only factors involved. Initial separation of the particles from each other, adsorption, electrical repulsions, surface tension, plastic inner friction and other factors have likewise a considerable influence. These may be called into operative play in a homogeneous composite with the use of certain substances and by subjecting the components to certain treatment. The tannin used by Acheson will not serve, as it apparently lacks sufficient protective strength to stabilize numerous particles above colloidal size. Substances have been found, however, which possess the property of stabilizing in liquid form up to about 40 per cent. by weight of carbonaceous particles, many of which are above colloidal size. It has also been found that particles considerably above colloidal limits in size may be simultaneously stabilized and peptized. When a substance is dissolved, it gives up a layer to the surrounding liquid. When peptized, some dissolving usually takes place, but the particles take up a part of the liquid (Zsigmondy, "The Chemistry of Colloids," **1917,** p. 9). It has now been ascertained that carbonaceous substances conchoidal in fracture and so seemingly crystalloidal as coal and like carbonaceous substances are peptizable. Even semianthracite is susceptible to some peptization, while bituminous coals and lignites lend themselves readily to such treatment. The carbonaceous substance, when peptized, becomes to a certain extent spongified and cavitated, thereby reducing the apparent specific gravity and hence the tendency to settle. While the chief function of the peptizing agent used in some cases is to peptize the particles, it has a marked dissolving and stabilizing effect as well, which is an accompaniment of its peptizing action and which is particularly noticeable at temperatures above normal. With reference to stabilizing two or more immiscible or partially miscible liquid hydrocarbons in each other, the interesting scientific fact has been disclosed that stability may also be readily obtained.

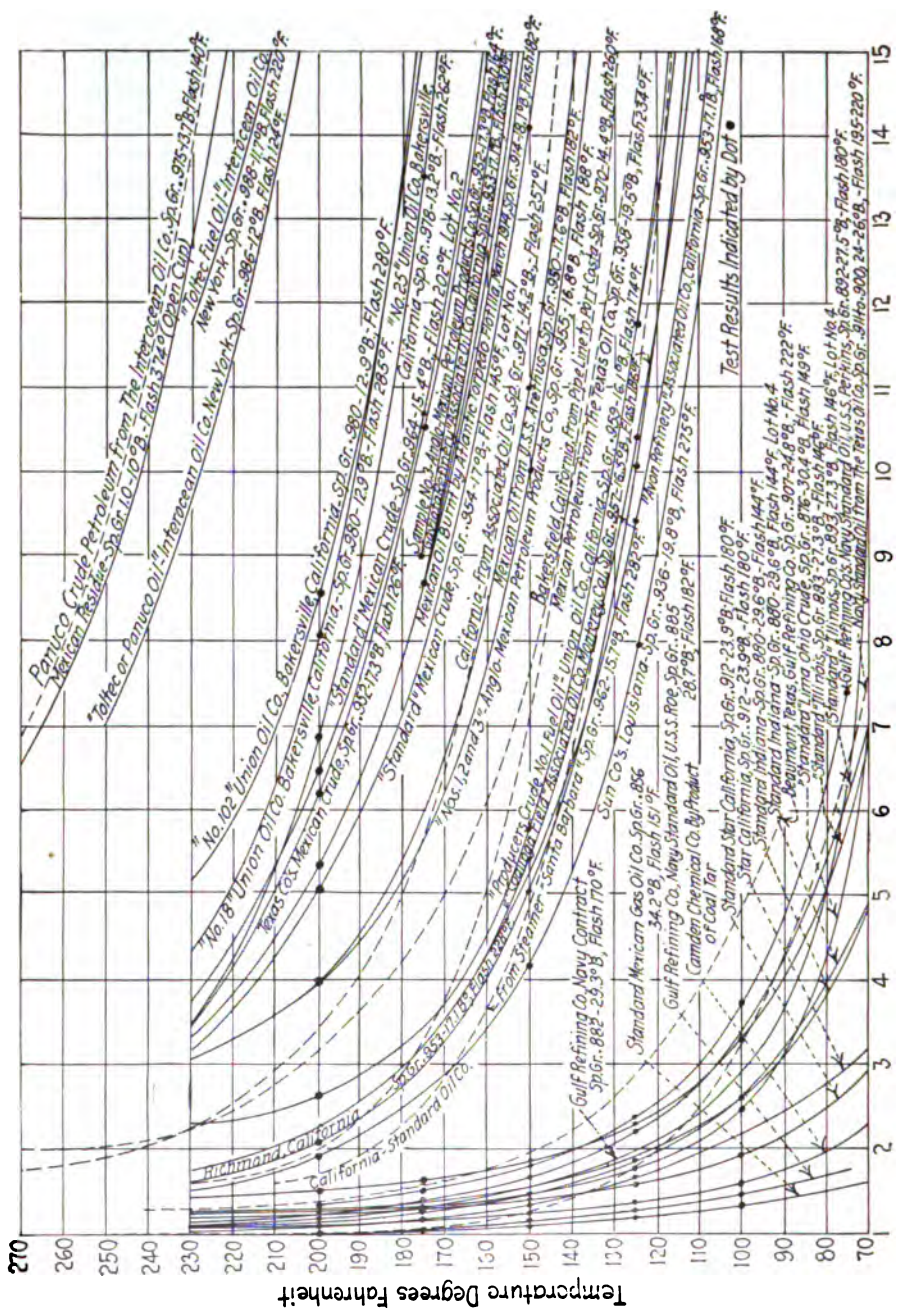


FIG. 276.—Temperature-viscosity diagram of fuel oils.

A number of distinct or distinguishable methods of achieving stability have been evolved. Three of these processes will be listed here. First, it is possible to stabilize particles by the use of certain protective substances. Soap and alkaline solutions may be mentioned. Some of these are operative not only upon colloidal coal in oil but also upon particles in size far above colloidal dimensions. Of the fixateurs, a typical substance is a variety of lime-rosin grease, specially prepared, in which lime, rosin and water are incorporated with heat and circulation into an oil carrier. The formula for a suitable grease is 83.5 per cent oil 10 per cent rosin, 5 per cent lime, and 1.5 per cent water. An

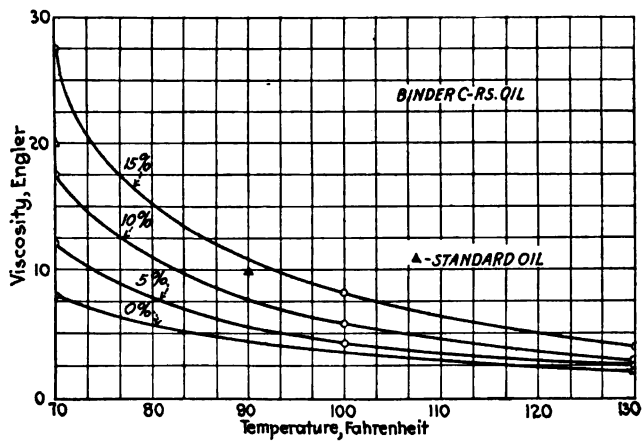


FIG. 277.—Blended oil curves.

amount of such grease which adds usually from ½ to 1½ per cent of saponified rosin to the fuel is homogenized, emulsified and saponified with the principal components. Second, it is possible to peptize bituminous coals and some other solid carbonaceous substances, to a limited but sufficient extent for stabilizing purposes, by the addition of coal distillates, such as tars and middle fractions, and by subjecting the mixture to a special heat-treatment below the flashpoint temperature. In the case of creosote, a small percentage is added and heat treatment at from 65 to 95°C. is employed. Third, by intensive grinding it is possible to reduce coal to colloid size, or practically so, and thereby to achieve the stability inherent in smallness of dimension. These and other measures are readily combined so as to adapt the stabilizing treatment to the specific gravities, surface tensions, vis-

cosities and association tendencies of the several ingredients. It is entirely possible to stabilize in mineral oil, in readily liquefiable form, up to 55 per cent of foreign substances divided between the liquid and solid ingredients derived from coal. A very suitable fuel consists of 30 per cent coal, 10 per cent coal-tar distillate and 60 per cent fixated mineral oil.

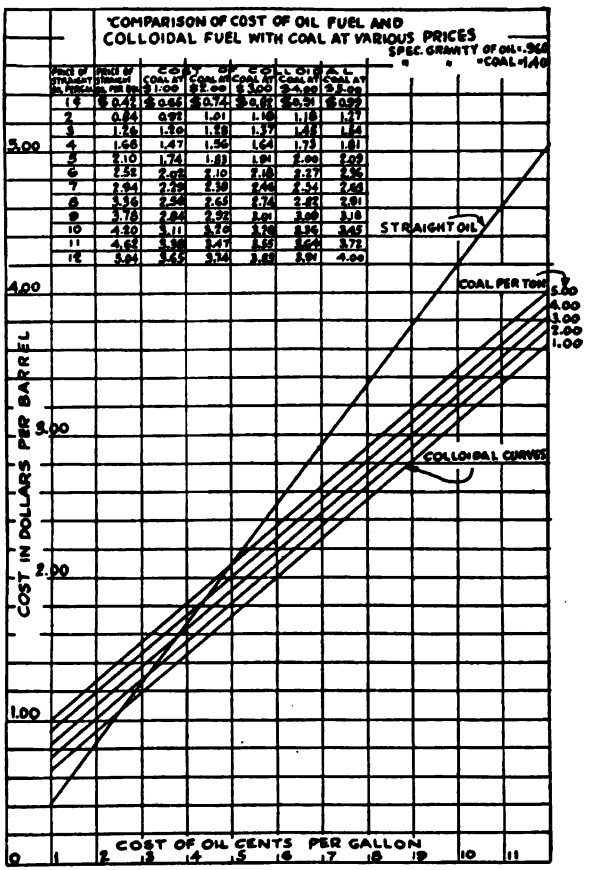


FIG. 278.—Cost chart, reproduced from a pamphlet on "Colloidal Fuels, Properties, Tests and Costs," by Lindon W. Bates, 62 London Wall, London, England.

In general, with a good quality of "fixateur," or peptizing agent, one may regulate stability by varying the amount used. Broadly speaking, the less the degree and duration of the desired stability, the lower the temperature, the fewer particles intro-

duced and the smaller their size, the less agent need be employed. If a paste fuel is to be produced, less agent may be required than if a liquid fuel is to be produced. A tendency to early, complete and consistent gel is promoted by somewhat larger amounts of agent than would be used simply to stabilize the particles in liquid fuel. Such amounts of agents should be used as will provide adequate stability at the temperatures of storage and preheater.

Mobile pastes may be made carrying as much as 75 per cent, more or less, of particles. Mobile gels may be made from liquids or pastes. Colloidal fuel may be a combination of these forms. In these forms and between these approximate ranges, a great number of liquid or mobile fuels may be prepared.

In the case of liquid colloidal fuel, after a completely liquid period of some days or months, the fuel may tend to gel from the bottom of the container up. The viscosities of the gel or lower stratum and of the so-called "serum" or upper stratum are different and the gel may carry more particles; but the fuel retains its atomizable character, and, in the case of both strata, the several components are present and are simultaneously combustible. Pumping, agitation or heat causes the gel to revert to a liquid and in some cases this will result even from a tap on the wall of the container. The colloidalizing treatment promotes the gel formation at the same time that it artificially stabilizes the particles. The creation of a gel even in its early stages materially assists stabilization, inasmuch as particles and droplets do not settle readily through a gel.

Colloidal fuel is a composite in three states of dispersion: solution, colloid and suspension. Some of the particles pass through a filter, many do not. Many are microscopically visible and measurable, others are not. Some display rapid Brownian movement, others slower, others no such motion. A cube of coal, one centimeter on each side, exposes a surface of six square centimeters. Such a cube pulverized so that 85 per cent passes through a 200-mesh screen exposes a surface of about 1,872 sq. cm. The dispersity or ratio of surface to volume has increased slightly over 300 times. Such a cube reduced so that the particles are 0.1 in size, that is, are just of colloidal size, exposes a surface of 60 sq. m., an increase in dispersity of 100,000 times. (Ostwald, "Theoretical and Applied Colloid Chemistry," **1917,** p. 118.) In colloidal fuel, a material amount, if not the bulk, of the carbonaceous particles remains in the product when

produced greatly above colloidal size and above the colloidal borderland.

A judicious and proper selection of the components to be made into colloidal fuel is of importance to the success of the operation. All classes of carbonaceous substance susceptible to reduction to particles by pulverizing or otherwise, are suitable for combining with liquid hydrocarbon under the process of creating colloidal fuel. For instance, anthracite, semianthracite, bituminous and semibituminous coals, as well as lignites and peats, are usable. Anthracite culm, dust and slush, also bituminous and lignite slack screenings and dust, and coal "seam dirt," of suitable qualities are all available. To this list may be added pressure-still, smelting and gas house coke and charcoals. Various grades within these groups have been successfully employed. It is also possible to use certain cellulosic and semi-cellulosic by-products, such as waste from starch, corn and flour factories, also wood pulp, wood dust, and disintegrated peat and lignite. Woods, when suitably pulverized, may also be combined under the process with liquid hydrocarbon. Carbonaceous substances of comparatively high ash and sulphur contents may be used. When colloidal fuel is burned, the ash in the particles of carbonaceous substance, as a result of pulverizing and colloidalizing, does not slag, but goes off to a large extent with the gases and the remainder falls to the bottom of the furnace, mostly as fine powder like pumice. The sulphur content may be averaged down by combining the carbonaceous substance with liquid hydrocarbon containing less sulphur proportionately. Several kinds of carbonaceous substance together may be used.

The carbonaceous substance should be reduced by pulverizing or otherwise, so that about 95 per cent passes through a 100-mesh screen and 85 per cent through a 200-mesh screen. Finer reduction is advantageous but is not essential to the process. In fact, even coarser particles may be temporarily or partially stabilized adequately for certain fuel uses. In a batch of coal pulverized to pass through a given screen, it is known that some particles are produced which are smaller than those which barely pass. If, for example, coal is ground so that 99.7 per cent passes a 100-mesh screen, 98 per cent a 200-mesh screen and 85 per cent a 300-mesh screen, about 70 per cent will be found to actually pass a 400-mesh screen. Rapidly diminishing amounts pass finer screens. The colloidalizing treatment does somewhat

reduce the particle size, but in colloidal fuel as produced many particles are found well above colloidal size. In fact, over-peptization creates an unstable composite. For the reduction of the carbonaceous substance to the size mentioned, any suitable mechanical, electrical or chemical means may be used, though an ordinary coal pulverizing ball or tube mill is most economical.

In general, all liquid hydrocarbons which are usable as liquid combustible, miscible or not with others such as oils, tars and

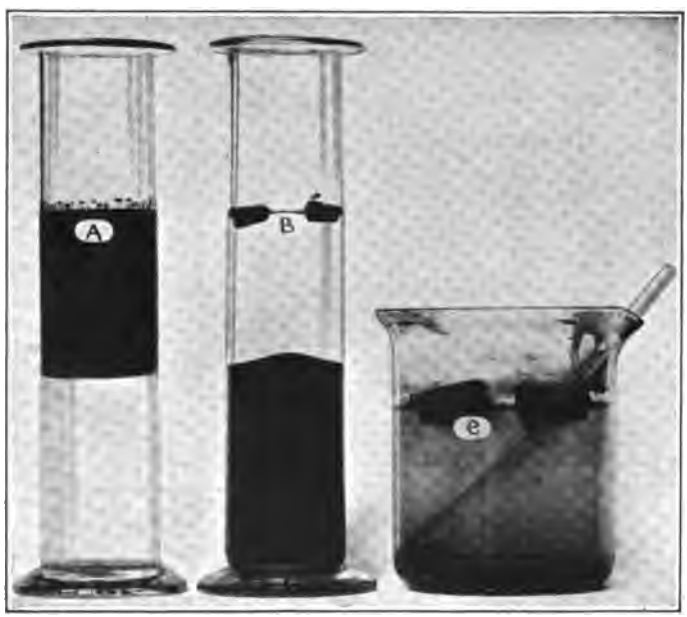


FIG. 279.

Fuel oil floating on water. Colloidal fuel sealed under water. Colloidal fuel kept under water one year.

pitches, may be used as a dispersion medium for particles of carbonaceous substance to form colloidal fuel. The product has been successfully made with all liquid hydrocarbons tried; including various fuel oils, pressure-still oil or tar, and coal tar both by-product of coke ovens and gas houses. By the term "pressure-still oil or tar" is meant the residual left from topping and cracking a paraffin-base oil in pressure stills. Liquid hydrocarbons of even higher sulphur and water content than would otherwise be acceptable for liquid fuel may be used, inasmuch as

it is possible, on colloidalizing, to average down these factors. Solid hydrocarbons are also utilizable when liquefied, provided the liquid falls within the above mentioned groups. Several liquid hydrocarbons may be blended.

In order to carry in liquid form a high percentage of carbonaceous particles, it is found advantageous that the liquid hydrocarbon should have approximately a certain viscosity which is readily obtainable. A lesser viscosity will not prevent the production of collodial fuel. It merely tends to reduce the percentage of particles which may be introduced into liquid

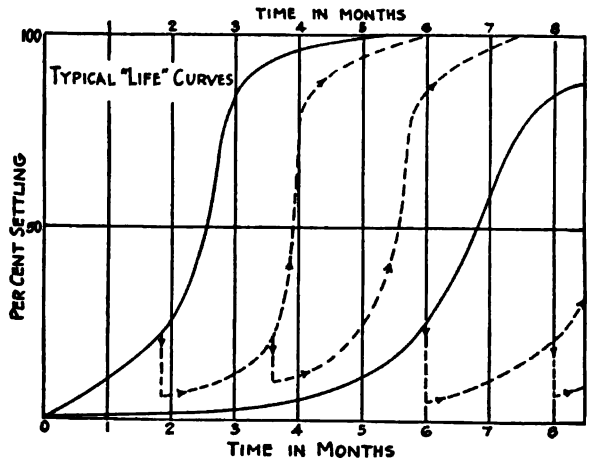


FIG. 280.—Life curves of colloidal fuel, showing prolongation by reagitating after initial setting.

hydrocarbon without changing the stability or character of the product. If it is desired to form a colloidal fuel paste or gel, the question of the initial viscosity of the liquid is of lesser moment. If the viscosity of the liquid hydrocarbon or hydrocarbons selected to constitute the dispersion medium is too great to yield a liquid product, in view of the amount of particles it is desired to introduce, viscosity may be reduced by blending with the liquid a "cut-back" consisting of other suitable liquid hydrocarbon. If the viscosity is less than the figure desired, in view of the amount of carbonaceous substance to be introduced and the character of the composite sought, viscosity may also be raised by blending with the liquid medium suitable liquid hydrocarbon.

TABLE CV.—TYPICAL RESULT OF STEAM TESTS ON U.S.S. "GEM," S.P. 41, 1918

Fuel	Colloidal fuel				Navy fuel oil	
System	Standard	Schutte & Koerting		Mechanical	1.7 mm.	Burners
Test number	2.0	4.0	6-B	12.0	3.0	6-A
Date	April 18	April 30	May 3	June 22	April 19	May 3
Duration, hours	2.0	2.25	0.67	3.17	2.0	1.5
Feed water temperature entering heater	72.1	83.3	81.0	95.3	77.5	71.3
Feed water temperature entering boiler	233.0	195.3	229.0	218.0	223.0	177.0
Flue gas temperature, average		745.5	668.5	644.5	629.5	661.5
Air temperature outside	45.2	60.6		72.0	60.5	
Air temperature boiler room	66.7	75.6			65.8	
Air temperature engine room	81.0	80.0	68.0	82.2		67.0
Fuel temperature	173.5	159.8	155.0	139.0	134.3	140.0
Fuel pressure, pounds	131.8	149.5	156.5	101.0	96.1	125.90
Draft uptake in W. G	0.05	0.05	0.05	0.05	0.05	0.05
Draft pressure, wind box, in W. G	0.73	0.71	0.70	1.08	0.72	0.66
Vacuum	25.0	24.8	25.8	24.7	26.0	25.3
Barometer	29.88	29.9I	25.90	29.71	30.35	29.90
Smoke average, per cent	30.00	0–10	0–10	0–10	10.0	0–10
CO_2		8.5	7.0	11.2		8.6
Boiler pressure, pounds gage	208.4	249.0	240.0	232.0	235.0	220.0
Engine pressure, pounds gage, average	73.2	86.2	117.5	119.0	90.8	85.45
Intermediate pressure, pounds gage, average	17.35	22.9	35.0	35.4	25.0	22.8
Revolutions per minute	214.5	231.6	260.5	268.2	243.5	230.5
Indicated hp. main engines	439.0	514.0	677.6	851.4	569.0	530.4
Knots by log	11.0	13.64		14.64	12.25	
Knots by Sanborn gage	11.0	13.4	14.18			13.3
Fuel per hour, pounds	950.0	1,030.0	1,050.0	1,493.0	938.0	1,000.0
Assumed water rate, pounds per indicated hp	24.3	23.5	24.2	24.8	24.0	
Steam per hour from and at 212°F	10,970.0	12,850.0	16,950.0	21,300.0	14,200.0	13,250.0
Factor of evaporation	1.029	1.071	1.035	1.048	1.039	1.088
Evaporation per hour	10,660.0	12,000.0	16,370.0	21,100.0	13,660.0	12,200.0
Pounds water per pound fuel	11.25	11.65	15.6	14.15	14.57	12.2
B.t.u. per pound fuel	17,100.0	17,100.0	17,100.0	17,600.0	18,500.0	18,500.0
Evaporative efficiency, per cent	65.5	70.7	91.5	84.2	79.4	69.6
Pounds water per square feet heating surface	4.06	4.56	6.23	8.03	5.19	4.64
Pounds fuel per indicated hp. main engines	2.16	2.0	1.55	1.75	1.65	1.9

[1] U.S.S. "Gem," 1918.

TABLE CVI.—DATA AND RESULTS OF BOILER TESTS OF COLLOIDAL FUEL, 1919

	Grade 13	Gaade 14	Mexican reduced fuel oil (Viscosity 1,104°Engler, sulphur 4 per cent)			
			Test 1	Test 2	Test 3	Test 4
1. Grate surface, square feet						
2. Total heating surface, square feet	4,840.0	4,840.0	4,840.0	4,840.0	4,840.0	4,840.0
3. Date	3/24	4/21	3/7/19	3/10/19	3/11/19	3/12/19
4. Duration, hours	8.0	8.0	8.0	8.0	8.0	8.0
5. Kind of liquid colloidal fuel, grade	13.0	14.0				
6. Steam pressure by gage, pounds per square inch	81.8	80.8		82.8	80.60	76.10
7. Temperature of feed water entering boiler, degrees	79.3	111.4		109.0	106.7	103.6
8. Percentage of moisture in steam or number of degrees of superheating, per cent or degrees	2.8	2.8				
9. Percentage of moisture in liquid colloidal fuel, per cent						
10. Liquid colloidal fuel per hour, pounds	1,286.0	1,076.0	1,159.5	1,146.5	1,054.7	982.75
11. Liquid fuel per square feet grate surface per hour						
12. Equivalent evaporation per hour, from and at 212°F., pounds	17,486.0	15,942.0	16,200.0	17,202.0	16,567.0	14,632.0
13. Equivalent evaporation per hour, from and at 212°F. per square foot heating surface, pounds	3.61	3.29				
14. Rated capacity per hour from and at 212° pounds	403 b.hp.	403 b.hp.	403.0	403.0	403.0	403.0
15. Percentage of rated capacity developed, per cent	126.0	115.0	110.6	122.0	118.0	105.0
16. Equivalent evaporation from and to 212° per pound of any dry coal pound	13.6	14.72	13.97	14.85	15.51	14.89
17. Equivalent evaporation from and at 212° per pound of combustible, pounds						
18. Calorific value of pounds of fuel by calorimeter, B.t.u	17,200.0	16,670.0	18,482.0	18,482.0	18,482.0	18,482.0
19. Calorific value of pounds of combustible by calorimeter, B.t.u						
20. Efficiency of boiler, furnace, and grate, per cent	76.8	85.3	73.3	75.94	79.46	76.8
21. Efficiency based on combustible, per cent						

Average efficiency of Mexican reduced fuel oil 76.37 per cent.

While blending was at first mainly a problem of thickening thin oils to suitable *minimum* viscosity to permit of practicable amounts of the "stabilizer" or "fixateur" being used, it later became rather a question of suitable maximum viscosity, so that too thick a fuel did not result. It might be thought that this latter condition simplifies the stablizing problem, in so far as stability depends upon viscosity. This is partly true, but not entirely. In very viscous oils, such as Mexican Panuco, etc., there is a strong tendency for "free carbon" and suspended carbon to clot.

The viscosity of fuel oil diminishes rapidly with rising temperature. For effective atomization of fuel oil through mechanical burners, the viscosity should be reduced by preheating to about 8° Engler. Higher viscosity may be used, particularly with other types of burners. The permissible viscosity depends somewhat upon the pressure of injection. For the original naval fuel purpose, colloidal fuel was made having substantially the above viscosity at 150°F.* While at normal temperatures, colloidal fuel containing high percentages of coal may resemble a heavy oil in viscosity, its viscosity requires less heat to reduce than oil, owing to the presence of the solid particles. The normal viscosity of colloidal fuel may be low or high, according to the ingredients, and stabilization is not due merely or primarily to high viscosity of the medium. In fact, a stable fuel may be made with a "cut-

Compositions, colloidal fuels	Grade 13, per cent	Grade 14, per cent
Coal		30.0
Coal (Pocahontas)	30.0	
Coal tar, etc.		12.0
Fixateur	1.5	1.2
Mexican reduced	28.8	
Texas navy oil	8.5	6.8
Pressure-still oil	31.2	50.0
	100.00	100.00

Analysis, grade 13	
Ash	3.20 per cent
Sulphur	1.27 per cent
Viscosity, 70°F	67.5°Engler
Sp. gr. 70°F	1.0431
Flash	250°F.
Fire	285°F.
Moisture	0.2 per cent

Grade 14
Ash 2 per cent, sulphur 0.2 per cent

* S. E. SHEPPARD, "Colloidal Fuels, Their Preparation and Properties," *J. Ind. Eng. Chem.*, **13** (1921), 37.

back" whose normal viscosity is less than that of the chief oil base.

In regard to flash point, British naval specifications are 175°F. closed-cup, or 200°F. open-cup. United States naval specifications are 150°F. closed-cup, or 175°F. open-cup. The addition of coal to fuel oil raises the flash point of the composite above that of the base oil. Consequently, the flash point of colloidal fuel is usually considerably higher than that of fuel oil. This is of advantage so far as preheating is concerned, since it is not necessary, as it is with some oils, to preheat over the flash point in order to atomize.

With reference to the apparatus needed to produce the composite, one may say that it consists chiefly in suitable mechanism for pulverizing carbonaceous substance and blending the fuel and "fixateur" components. Existing machinery, with very slight modification, is quite suitable and may be adapted to serve as a unit for making colloidal fuel. The carbonaceous substance may be pulverized simultaneously with the treatment necessary for combining it with the liquid hydrocarbon. The "fixateur" may be made before hand or its components may be united when the fuel constituents are treated.

The problem of burning colloidal fuel is simply that of burning a heavy oil. No material change in oil burning installation is necessary. To use the pastes, however, it may be necessary to modify slightly the installation and increase the pressure to convey the fuel to the atomizer. In the case of a gel which is broken up by pumping or which liquifies in the preheater, more pressure alone is required. Burners acceptable for oil fuel may be used for colloidal fuel and it is advantageous to fit the burner with a steam or air pipe for cleaning purposes.

The accompanying tables illustrate the burning qualities of colloidal fuel on typical marine and land tests. On the U.S.S. "Gem," colloidal fuel was compared with standard Navy fuel oil and on shore with Mexican reduced fuel oil. On shipboard saponified fuels were used, while at the land station both this variety and saponified and peptized fuels were demonstrated. Excellent results were obtained with a liquid fuel, even using 40 per cent pulverized anthracite rice containing as much as 25 per cent ash in the coal. Colloidal fuel gave results equal to or better than fuel oil.

Colloidal fuel made by the process outlined enjoys many

features besides adequate stability. The advantages of the composite over coal are the advantages of liquid fuel over solid fuel, to which are added the special advantages of the composite as a liquid or mobile fuel. "One million B.t.u. in fluid will on an average equal 1,610,000 in hand-fired and 1,327,000 in mechanically-fired solid fuel."* The following table expresses in terms of ratios the comparative efficiencies of fluid *vs.* solid fuels, oil representing unity:

Service	Fluid fuel	Solid fuel		
		Hand-fired	Stoker-fired	Pulverized
Navy and Merchant Marine....	1	1.609		1.333†
Locomotive.....	1	1.487		
Major power stations.....	1	1.257	1.156	
Major power catalog.....	1	1.135	1.114	
Minor power stations.....	1	1.154 1.340	1.200	
Average.....	1	1.390	1.157	1.333

Colloidal fuel, furthermore, enables the flame used in metallurgical processes to be given the degree of hardness or softness desired. It is well known that coal gives a soft flame while oil gives a hard one. In certain steel and other metal processes the character of the flame as distinguished from the degree of heat is of supreme importance. To obtain a flame of the character desired, all that is necessary is to make up the composite with such amounts and kinds of components as will give the desired heat units and the flame of the character required.

* "Colloidal Fuels, Their Relation to Coal, to the Production of Power and Heat and to Fire Prevention and Insurance," LINDON W. BATES, 1919, p. 13.

† U.S.S. "Gem," 1918.

Aside from stabilization, the colloidal fuel process has developed in several collateral directions. For example, if a crude oil instead of a fuel oil is used with a volatile coal, the composite may be topped or distilled during or after the combination or recover mixed coal and oil distillates. This feature is of great importance, because it allows coal distillates, to be recovered without the expense of installation of coke ovens. A film or spray system of oil topping is quite suitable for the composite, with minor adjustments. The combination of purification of coal by flotation and colloidalizing has also been investigated.

With reference to the saving involved in colloidal fuel, one may divide this into two classes: There is first the conservation involved in the use of less oil. In the age that has arrived the refinable oils of the United States and abroad have become far too potentially valuable to burn as fuel, when crude or even partially refined. The large proportion of sulphur in Mexican oil is poison to steel, to alloy steels, to copper and to brass, and to the economizers of power plants. The metal purchaser and manufacturers who seek salvation by using straight pulverized coal are confronted by its disadvantages—high installation costs, large space occupied, the necessity of drying, and the limitations and hazards of dust and storage. Colloidal fuel allows also certain liquid hydrocarbons which have a limited market today to be utilized to advantage. Carbonaceous substances which are too broken to be utilized as lump coal are excellent for colloidal fuel. Vast quantities of carbonaceous substances high in B.t.u. content but unserviceable at present may be used to advantage. Aside from this economic benefit, there is a material saving in cost in the use of colloidal fuel over coal, hand-fired, stoker-fired or pulverized, and over the use of oil fuel in many if not in most localities. Of course, there is the greatest margin of economy in localities where oil and lump coal are relatively dear, but other cheap carbons are available. These conditions prevail in numerous localities in America and Asia and in practically every country of Europe. The saving in cost varies from a few per cent up to over 50 per cent in the case of certain pastes. "When 1,000,000 B.t.u. in colloidal fuel cost less than 1,000,000 B.t.u. in fuel oil, colloidal is the cheaper. On an average, when the cost of 1,000,000 B.t.u. in colloidal is less than the cost of 1,610,000 B.t.u. in coal, hand-fired, or to the cost of 1,327,000 B.t.u. in coal, stoker-fired, then colloidal fuel is the cheaper."

This chapter has been prepared from the several published articles and patents relating to colloidal fuel, from which extracts have been taken verbatim. Among the reports of the Submarine Defense Association may be mentioned: "Colloidal Fuel Composites of Oil and Carbon," by LINDON W. BATES; "Navy Fuel Oil Specifications and Colloidal Fuel," by DR. S. E. SHEPPARD; and "Tests of Colloidal Fuel and Pulverized Coal on Shipboard," by HAYLETT O'NEILL. Since the War, among other articles and pamphlets, the "Report upon Colloidal Fuel and Recommendation to the Fire Council by the Fire Underwriters' Laboratory" deserves special mention. The principal United States patents issued to date covering the colloidal fuel product, process and apparatus are the following: 1,390,228 to 1,390,232, inclusive; 1,382,457 and 1,373,704, to LINDON W. BATES.

In conclusion one may say that a new series of fuels has entered the market which will be beneficial both to the oil and to the coal industry. Heretofore coal and oil have traveled side by side, enemies not friends. The ultimate future is unto coal since oil is relatively short lived. A hundred years must find its story told. There will still be coal when there is no more oil, save as it be distilled from shale. In this time, however, of half a world calling for industrial resurrection all the coal that can be mined and all the oil that may be won are needed. Each should support the other. Through colloidal fuel the quantity of liquid fuel available may be doubled at the present rate of production of fuel oil.

CHAPTER XIII

NATURAL GAS*

By

Samuel S. Wyer†

Natural gas is a highly combustible gas made by a secret process of nature. It is not a chemical compound, as popularly supposed, but a mechanical mixture of several combustible and diluent gases and vapors thoroughly diffused through each other, the number and exact proportion of the various natural constituents varying for the different localities and somewhat during the working lives of individual wells. Natural gas is the only fuel made by nature in refined form ready for immediate gaseous use. While natural gas is a natural product made by nature it is no more natural than any other mineral like coal, oil, or ore. The word "natural" came into common use so as to contrast this gas with manufactured or artificial gas. Unfortunately the term "natural gas" gave the fallacious impression that natural gas was a free and unlimited resource.

Natural gas is obtained by drilling down, usually about one-half mile, below the earth's surface, into the porous rock in which the gas is stored by nature. Nature by some unknown process has compressed the gas into the minute spaces between the sand grains in the rock. An impervious covering over the gas sand-rock was, of course, a condition precedent for holding the gas in this underground reservoir. The drilling through this impervious covering taps the sand-rock reservoir and permits the gas to come up through the opening to the surface above. In this the gas travels by its own inherent tendency to expand. From the surface the gas then is led through pipes to the ultimate consumer, frequently several hundred miles away. To supplement the inevitably declining natural pressure, compressors ordinarily

* Some of the material in this chapter is taken from the author's Smithsonian Inst. *Bull.* **102**, Part 7, on "Natural Gas; Its Production, Service and Conservation."

† Consulting engineer, Columbus, Ohio.

must be used in order to increase the pressure enough to permit the gas to pass through the pipe lines.

GROWTH OF NATURAL GAS INDUSTRY

The number of producing natural gas wells in the United States has increased from about 1,800 in 1891 to about 40,000 at the present time. The number of domestic consumers has increased from 500,000 in 1902 to 2,500,000 at the present time. The number of domestic consumers is increasing faster than the number of producing wells.

The best available data show approximately the following:

Number of acres of land known or believed to contain natural gas	16,000,000
Present fair value of property	*500,000,000
Total horsepower of compressors used in transmission	350,000
Number of towns in United States having natural gas	2,000
Number of domestic consumers	2,500,000
The annual consumption (1917) of the domestic consumers amounted to	259,000,000,000 cu. ft.
The annual consumption (1917) of the industrial consumers amounted to	536,000,000,000 cu. ft.

Of all the towns in the United States that have gas about one-half have natural gas, and of all the gas sold as a public utility service in the United States about 75 per cent is natural gas.

West Virginia, Oklahoma, Pennsylvania, Ohio, California, Louisiana, Kansas, Texas, Wyoming, New York, Arkansas, Illinois, Kentucky and Indiana afford about 99 per cent of the entire production in the United States.

CHEMICAL CONSIDERATIONS

Natural gas is made up primarily of methane, or marsh gas, with small quantities of other hydrocarbons and, in some cases, nitrogen. There is considerable variation in the composition of gas from different fields.* Gasoline vapors frequently are mixed in with the permanent gases.

* For further analytical data, see "Problems in Natural Gas Engineering," by THOMAS R. WEYMOUTH, *Trans. Am. Soc. Mech. Eng.*, **34**, 728 and 729; and U. S. Bureau of Mines, *Tech. Paper* **109**, on "Composition of Natural Gas Used in 25 Cities," by G. A. BURRELL and G. G. OBERFELL. On the composition and analysis of natural gas, see also HAMOR and PADGETT, *lib. cit.*

Heating Value of Natural Gas.—The heating value of natural gas will vary largely for different fields, ranging from about 700 to 1,200 B.t.u. per cubic foot.*

Weight of Natural Gas.—The specific gravity of natural gas with reference to air as unity usually will be between 0.6 and 0.7, so that the weight will be from 45 to 55 lb. per 1,000 cu. ft.

Variations in Specific Gravity of Natural Gas.—Different wells from the same field may vary largely. The general tendency of natural gas from most wells is for the gas to become heavier as the wells become older. Variation in specific gravity has a direct bearing on the accuracy of many types of meters. It will also affect the air-entraining power of air-mixers, which, in the last analysis, are merely air injectors and in this way it may affect the amount of primary air that may be drawn into the burner. In some cases this variation may alter the amount of gas that will be passed through the mixer opening of the lava tip in the so-called luminous flame heater.†

Combustion of Natural Gas.—When natural gas is burned completely the carbon content will burn to carbon dioxide and the hydrogen content to water vapor, each cubic foot of gas making about 7 cu. ft. of carbon dioxide and 2 cu. ft. of steam. This steam, when condensed, will make usually about 10 gal. of liquid per 1,000 cu. ft. of gas burned. Because of the large water vapor content of the combustion products, there are some industrial uses where this is troublesome, and it must be reckoned with in the employment of natural gas.

The combustion—that is, the burning of natural gas—can take place only by first mixing the gas with the proper proportion of atmospheric air. The exact amount of air necessary will vary with the B.t.u. content of the gas, but for most gases will average about 9½ cu. ft. of air for each cubic foot of natural gas. In order to have perfect combustion, it is necessary to mix some of the air with the gas before it reaches the flame; that is, apply the fundamental principle of the bunsen burner. The air-mixer is merely a small air-injector, in which the velocity of the gas, as it

* For data, see WEYMOUTH and, G. A. BURRELL and G. G. OBERFELL, *cit. supra.*

† For further discussion, see U. S. Bureau of Standards, *Tech. Paper* **94** on "Effusion Method of Determining Gas Density," by J. D. EDWARDS; *Tech. Paper* **359** on "Efflux of Gases Through Small Orifices," by EDGAR BUCKINGHAM and J. D. EDWARDS; and *Tech. Paper* **89**, "A Specific Gravity, Balance for Gases," by J. D. EDWARDS.

passes through the small orifice in the mixer, is used to create a sucking action of drawing air into the mixer, and by so doing mix it with the gas.

The Bureau of Standards, Washington, D. C., recently has conducted some tests which demonstrate that the form of the mixer throat has a vital bearing on the results that can be obtained, and these tests also show that most types of commercial mixers now on the market can be improved greatly.*

Only Gaseous Hydrocarbon Complexes Can be Used in Public Utility Service.—Hydrocarbon complexes exist in solid, liquid, vaporous and gaseous forms. However, only the gaseous can be made use of as a public utility service by public utility consumers. The solids could not be made to pass through the lines; the liquids, if mixed with gas, would interfere with the gas flow; and the vapors, due to changes of temperature and pressure, are precipitated in the form of liquids, and then not only interfere with the continuity of the service, but also injure transmission lines. For this reason drying of the natural gas in the field by separating the vapor and liquid constituents is desirable from a public utility viewpoint.†

Gasoline Removal is a Separation and Not an Alteration.—The removal of the gasoline vapor does not make the remaining gas artificial or manufactured. In the gasoline separation no substances are added that produce chemical changes, but the procedure is a mechanical separation of the gasoline by a suitable compression, absorption or refrigeration process.

In the absorption process the separation of the vapors is effected by forcing the mixture of gases and gasoline vapor through an absorbing oil which takes out the condensible vapors, and the gas passes on through and usually is sold in public utility service; the absorbed gasoline vapors are separated from the oil by heating it. In the compression process the mixture of gasoline vapor and gas is compressed. This precipitates the vapor into a liquid and thereby separates it from the gas. In the refrigeration process the mixture of gasoline vapor and gas is cooled artificially by refrigeration. This cooling results in the

* See I. V. Brumbaugh and G. B. Shawn, "How Natural Gas Burners can be Improved," 16th Annual Meeting, *Nat. Gas Asso. of Am.*, Cincinnati, O., May 16–19, **1921.**

† For further discussion, see pp. 25 to 27, Smithsonian Inst. *Bull.* **102,** Part 7.

precipitation of the gasoline vapor and its easy separation from the gas. This process usually is used only as an auxiliary aid to either the absorption or compression process.*

FUNDAMENTAL FEATURES OF DOMESTIC NATURAL GAS USE

Gas service is radically different from every other kind of public utility service in that the gas can not be used by the consumer as received, but—

First, must be mixed in proper proportion with another substance (atmospheric air);

Second, this mixture then must be burned completely;

Third, the flame must be directed so that the heat generated will get effectively into the food, air, water, or mantle that is being heated, with a minimum loss.

The results obtained will depend primarily on the gas utilizing appliance and the consumer's skill and care in operating. All these operating features are beyond the gas company's control, but are vital in determining the quality of the service produced by one consumer and the effect on the service of other consumers.†

In all domestic uses of natural gas relatively low temperatures are needed. For instance, all boiling operations would have temperatures usually in excess of 210°F., and no baking or broil-

* For further discussion, see the following publications of the U. S. Bureau of Mines:

Bull. **88,** "The Condensation of Gasoline from Natural Gas," by G. A. BURRELL, F. M. SEIBERT and G. G. OBERFELL;

Bull. **114,** "Manufacture of Gasoline and Benzene-Toluene from Petroleum and other Hydrocarbons," by W. F. RITTMAN, C. B. DUTTON and E. W. DEAN, with Bibliography compiled by M. S. HOWARD;

Bull. **120,** "Extraction of Gasoline from Natural Gas by Absorption Methods," by G. A. BURRELL, P. M. BIDDISON and G. G. OBERFELL;

Bull. **151,** "Recovery of Gasoline from Natural Gas by Compression and Refrigeration," by W. P. DYKEMA;

Bull. **176,** "Recent Developments in the Absorption Process for Recovering Gasoline from Natural Gas," by W. P. DYKEMA; and

Tech. Paper **10,** "Liquefied Products from Natural Gas, Their Properties and Uses," by I. C. ALLEN and G. A. BURRELL.

† For further discussion of gas use, see U. S. Bureau of Mines, *Tech. Paper,* **257,** on "Waste and Correct Use of Natural Gas in the Home." See also the bulletins of the Dept. of Home Economics, Ohio State Univ.,: *Bull.* **28,** "Effect of Gas Pressure on Natural Gas Cooking Operations in the Home," May, **1918;** and "Kitchen Tests of Relative Cost of Various (Five) Fuels for Cooking," Reprinted, October, **1918.**

ing operations need have temperatures above 500°F. This is in marked contrast with the high temperatures, 1,500 to 1,800°F., frequently necessary in industrial uses.

Confusion Between Intensity and Quantity of Heat.—There has been much confusion by lack of appreciation of the difference between the quantity of heat and the intensity of temperature that is obtained by the combustion of gas, and failure to appreciate that gas is merely a carrier of heat energy up to the point of combustion. There also has been a marked lack of appreciation that the B.t.u. content of the mixture which is actually burned at the flame is relatively low and practically the same regardless of the B.t.u. content of the gas. For instance, to burn 1 cu. ft. of 1,200 B.t.u. natural gas will require about 11 ft. of air, so that the B.t.u. content will be distributed over 12 ft., or about 100 B.t.u. per cubic foot of the mixture. To burn 1 cu. ft. of 1,000 B.t.u. natural gas will require about 9½ ft. of air, so that the B.t.u. content will be distributed over about 10½ ft., or about 95 B.t.u. per cubic foot of the mixture. To burn 1 cu. ft. of 600 B.t.u. manufactured gas will require about 5½ ft. of air, so that the B.t.u. content will be distributed over 6½ ft., or about 92 B.t.u. per cubic foot of the mixture. To burn 1 cu. ft. of 140 B.t.u. producer gas will require about 1 ft. of air, so that the B.t.u. content will be distributed over 2 ft., or about 70 B.t.u per cubic foot of the mixture.

When the atmospheric temperature drops below 70°F., the demands for heating service increase practically in a direct proportion to the drop in temperature. This results in a very variable, erratic and uncertain load as far as natural gas heating service is concerned and is responsible for most of the low pressure conditions.

DECLINING SUPPLY

The amount of natural gas used in the entire United States is on the decline. The peak load occurred in 1917, when there was an annual consumption of 795,000,000,000 cu. ft. This annual consumption declined to 660,000,000,000 cu. ft. in 1919, and all the present indications are that it will continue to decline for some time. The demand is greater than the available supply and the only chance for relief is to first curtail the use of industrial gas wherever feasible, and then teach the domestic consumer to use the gas more efficiently so as to cut down the

domestic consumer's demand and limit his demand to the amount of gas that will be available for service.

The rate of demand on natural gas has been so rapid, and the increasing demands of the domestic consumers so great, that the time is at hand when gas engineers must direct their attention to using powdered fuel, water gas and producer gas to replace the large amount of natural gas now used in industrial operations. For this reason, the natural gas industry is in a transition stage and the gas sales for the future will be largely to domestic consumers, since there will be a constantly declining amount of gas available for industrial work each year.

No manufactured gas can be made that will have the B.t.u. content that is available in natural gas, and no other utility service or commodity can be purchased that will give as large a number of B.t.u. per $1 of expenditure as can be secured with natural gas at $1 per 1,000 cu. ft. Everything in connection with the distribution and utilization of natural gas that ought to be done to bring about efficient use and greatly curtail the demand —in fact, bringing the demand down to one-third on the basis of still having the same service—must be done to use manufactured gas at all. Therefore, it would seem merely a matter of simple common sense to use natural gas as it ought to be used and by so doing eliminate the necessity of considering manufactured gas for many years to replace the natural gas now sold in public utility service.

Mixing Gases.—Natural gas has been used successfully for enriching manufactured gas, the resulting mixture being a better product and worth more than the original manufactured gas. However, the admixture of manufactured gas to natural gas must always result in a degradation of the natural gas; that is, lower its thermal value, since the heating value of the mixture will be lower than the heating value of the original natural gas. The mixing of the two gases is a relatively easy engineering problem, but the economic factors growing out of the lower heating value of the mixture must control the feasibility.*

In order to give usable service with mixed gas, it will be necessary to keep the ratio of the manufactured gas and the natural gas approximately the same, so that the specific gravity and heating value of the mixture will be fairly uniform. If there is any marked variation in specific gravity or B.t.u. content,

* See discussion by J. B. GARNER on p. 911.

immediate trouble will be experienced in gas-using appliances. It will not be possible to operate a manufactured gas plant at its full rating every day, and the average daily capacity must synchronize with the natural gas load fluctuations. For this reason it generally is considered unfeasible to use a low B.t.u. manufactured gas merely to supplement the supply of natural gas during the peak load period.

PERSPECTIVE ON GAS INDUSTRY

The public has been lulled into a state of indifference through the erroneous belief that, as natural gas became scarce, all that was necessary was to build plants manufacturing gas and especially to build by-product coke ovens to replace the beehive ovens now in use. The following relationship shows the marked changes that must be considered when natural gas can no longer be available:

The total amount of natural gas consumed in 1919 was	660,000,000,000 cu. ft.
The natural gas equivalent of all the manufactured gas made and sold as a public utility service in 1919 was	133,000,000,000 cu. ft.
The natural gas equivalent of all the by-product cokeoven gas that could be made in all the beehive ovens in the United States in 1919 was	78,000,000,000 cu. ft.

The above relationship emphasizes a feature all too frequently ignored; namely, that when natural gas is gone, the entire natural-gas industry must be revolutionized.

Factors Determining Value of Natural Gas.—The relative B.t.u. that can be secured by the expenditure of $1 for different fuels is shown below:

		B.T.U. OBTAINED FOR $1
Natural gas	@$1.00 per thousand	1,100,000
Kerosene	@ 0.20 per gallon	640,000
Gasoline	@ 0.30 per gallon	493,000
Manufactured gas	@ 1.25 per thousand	440,000
Alcohol	@ 0.40 per gallon	182,000
Acetylene—with carbide	@ 0.04 per pound	140,000
Electricity	@ 0.06 per kilowatt	56,000

However, the B.t.u. content alone is not the only criterion, since the purity of natural gas and the ease in handling gives it a

marked advantage over solid fuels and ordinary commercial gases. In many industrial operations the metal that is heated in the furnace will be injured by the presence of sulphur in the fuel. The almost universal absence of sulphur from natural gas gives it a marked advantage from this point of view.

Relative Cost of Natural Gas and Other Fuels for Cooking.—Based on actual tests* in cooking a dinner consisting of thick or Swiss steak, scalloped potatoes, spinach, bread, butter, rice pudding, coffee, cream, sugar, with portions for six people, the following relationships have been found:

		Cents
Natural gas (1- to 2-oz. pressure, short flames)	@$1.00 per thousand	1.1 cts.
Natural gas (4-oz. pressure, long flames)	@$1.00 per thousand	2.2 cts.
Soft coal	@ 6.50 per ton	2.5 cts.
Gasoline	@ 0.27 per gallon	4.6 cts.
Electricity	@ 0.03 per kilowatt	5.1 cts.
Coal oil	@ 0.15 per gallon	5.4 cts.

Relative Cost of Gas and Coal for House Heating.—The ordinary coal furnace using coal has a thermal efficiency of about 25 per cent; that is, 75 per cent of the heat energy in the coal is lost. A high-grade natural-gas furnace can easily have an efficiency of 80 per cent, so that only 20 per cent of the B.t.u. content of the gas will be lost. Therefore, in comparing the B.t.u. content of the coal with the B.t.u. content of the gas, it is necessary to appreciate that the efficiencies in natural-gas utilization can be very much higher than the efficiencies in coal utilization; and because of this fact 8,000 cu. ft. of natural gas used in an efficient furnace will be the equivalent of a ton of coal.

Natural-gas Consumption for Various Industrial Operations

	Cubic Feet of Natural Gas Consumed
Window glass—per box, single-strength glass	1,700
Window glass—per box, double-strength glass	2,500
Melting aluminum—per 100 lb. metal	283
Nut furnaces—per 100 lb. nuts made	193 to 245
Baker's ovens—per 100 lb. dough baked	126
Lead melting—per 75 lb. lead melted	1,000

* "Kitchen Tests of Relative Cost of Natural Gas, Soft Coal, Coal Oil, Gasoline and Electricity for Cooking," made by the Dept. of Home Economics, Ohio State Univ., June, 1917.

Ice making—per ton ice made	6,000 to 7,300
Flour mill power—per barrel flour made	275 to 300
Cotton gins—per bale cotton ginned, average per season	2,400
Open hearth steel—per ton metal	6,400
Brass melting—per 650 lb. melted	1,100
Gas engines—per indicated horsepower	9 to 11
Biscuit tile—per 1 ton biscuit tile made	20,000
Sewer pipe—per ton of pipe	11,800

ENRICHMENT OF ARTIFICIAL GAS WITH NATURAL GAS

By

James B. Garner*

The project of enriching manufactured or artificial gas with natural gas is of widespread interest because of the possibility it offers of providing a supply of a clean domestic fuel gas, uniform in quality, and of sufficient volume to meet the requirements of the public. This is particularly the case in regions where natural gas has been used.

There are in nature three potential sources of raw materials adequate for the production of a future domestic supply of manufactured gas: bituminous shale, oil, and coal. Artificial gas, as produced on a commercial scale, consists of the following varieties: shale gas, oil gas, producer gas, water-gas, carbureted water-gas, coal, and coke-oven gas.

Shale gas has been made and utilized with some degree of efficiency in Scotland, and considerable experimental work has been done in the United States looking toward the development and utilization of our vast beds of bituminous shale. With our present lack of engineering and technical knowledge regarding the use of bituminous shale as the future source of an adequate supply of manufactured gas, its geographic location and availability is such that bituminous shale cannot now be considered as an immediately available raw material.

Oil gas is the domestic gas of San Francisco, Oakland, Los Angeles, Portland, Tacoma, and San Diego. Oil is used as the basis of gas manufacture in these western cities because of the non-availability of cheap coal, while cheap oil is available. In

* Director of the Research and Development Department, Hope and Peoples Natural Gas Companies, Pittsburgh, Pa.

all other sections of the United States, gas oil or other products from petroleum are so expensive that the manufacture of oil gas is economically prohibited.

Producer gas, water gas, carbureted water gas, coal, and coke-oven gas have all been made and used with greater or less success for many years past. Coal seems to be the only raw material which is at present available as a basis for a future gas supply. Producer gas is unsuited for use as a domestic gas for two reasons: (1) Its high content of inert nitrogen, and (2) the excessive cost of cleaning, cooling, and distributing.

Coke-oven gas and coal gas of a high quality are made; but on account of the cost of installation and nonflexibility of the plants wherein these gases are produced, these processes of manufacture are unfitted for use in meeting the peak-load requirements of an adequate domestic supply.

Blue water gas, although lower in heating value than coke-oven or coal gas, can be made most economically, and in a plant which is cheap in its cost of installation and flexible in its operation. Blue water gas is at present the only rational basis for an adequate supply of clean, uniform fuel gas to meet peak-load public requirements. Blue water gas, carbureted by means of gas oil, cannot, under present market conditions on crude petroleum, be the kind of commercial gas for an adequate public supply. In addition, this use of the waning supply of crude petroleum is far from the conservation of one of our greatest natural resources. In order to carburet water gas of an initial heating value of 325 B.t.u. per cubic foot, so that it will have a heating value of 570 B.t.u. per cubic foot, it is necessary to use 3 gal. of gas oil per 1,000 cubic feet of gas. Assuming that the market price on gas oil is 12 cts. per gallon, the enriching of 1,000 cu. ft. of gas thus costs the producer 36 cts., without any overhead, production, or depreciation charges. Natural gas, as produced in the Appalachian and Mid-Continent fields, has an average heating value of 1,100 B.t.u. per cubic foot. It can readily be seen that less than 80 cu. ft. of natural gas has an enriching value equal to one gallon of gas oil. Natural gas can be mixed with blue water gas easily, safely, and without any overhead, production, and depreciation charges, and is, therefore, the ideal enricher of water gas in regions where natural gas is available.

The manufacture of a domestic supply of water gas, enriched with natural gas, serves two purposes:

1. It conserves in the highest possible manner our natural resources of coal, oil, and gas.

2. It insures to the public an adequate supply at all times of a clean, uniform gas at the lowest possible cost.

It is predicted that ultimately natural gas companies will not sell natural gas as such, but will utilize it in the highest possible way, *viz.*, as a means of enriching manufactured or artificial gas. Such use of this natural resource will insure to the public, for many years to come, a supply of gas at a cost otherwise impossible.

CHAPTER XIV

PRODUCER GAS TECHNOLOGY

By

F. W. Steere*

Producer gas is the cheapest artificial gas per B.t.u. that can be made from solid fuel. Moreover, the principal chemical and physical reactions involved in its manufacture are extremely simple; and the producer in which it is made can be of the simplest design, consisting of nothing more than a brick-lined shell with a grate in the bottom and a charging hole and a gas offtake on top. The gas from such a producer will be approximately the same as that from the most modern design with all mechanical features.

Notwithstanding these three indisputable facts, the application of producer gas to the industries of this country is still in the experimental stage with few exceptions, among the most prominent of which are the iron and steel industry, the manufacture of glass, and the firing of coal gas benches. Unquestionably, the main reason for the present lack of reliable information and data on the more general application of producer gas has been the abundance and low cost of our natural fuels. There has been no incentive to develop more economical methods as long as our natural fuels could be obtained at the very low figures that have prevailed in the past. However, it is quite possible that producer gas will be used more extensively in the future than in the past, if for no other reason than the increasing price of competing fuels.

One of the objects of this Chapter is to indicate some of the practical difficulties which have been encountered in adapting producer gas to various industries and, where possible, to suggest the remedies therefor. Oftentimes, more can be learned from a study of failures than from the consideration of successes. The percentage of producer gas installations which have not proved to be commercially successful is certainly high, and would seem to offer a fertile field for investigation.

* Steere Engineering Co., Detroit, Mich.

GAS ENGINEERING *versus* STEAM ENGINEERING

One of the most serious mistakes that has been made in the past is the failure on the part of the prospective buyer and his engineers to realize that producer-gas engineering is a business in itself and that it is not on any such basis as steam engineering. For example, when considering the installation of a steam power plant, the engineer in charge of the project has before him a wide range of more or less standard forms of apparatus from which to choose. There are many different types of stokers, boilers, engines, turbines, etc., any one of which will run successfully, as can be demonstrated by many successful installations. The problems is to select the apparatus best suited to the particular condition, with a possible slight variation in efficiency between the different types. Contrast this condition with a proposed producer gas installation. To illustrate this point, there may be cited the following experience: One of the most prominent engineers in this country became associated with an undertaking which involved the possible installation of a producer gas plant. Not being sufficiently familiar by personal experience with gas-producer work, he consulted some of the best-known engineers available on the subject. After listening to the arguments pro and con, it became evident that there were wide differences of opinion. More engineers were called in and more meetings held. Manufacturers of various producer gas equipment were consulted until, as far as could be determined, practically every person and company having a recognized right to an opinion on the subject had been conferred with. As a result of some 10 months effort to arrive at the correct solution of the problem, the following summary of conditions was found:

There was a complete disagreement, not only as to the type of producer best adapted to the job, but also as to all the auxiliary apparatus.

The kind of fuel to be used and the manner in which the gas should be handled after leaving the producers, were subject to as many opinions as there were engineers consulted.

In general, there was a complete disagreement on every point of fundamental importance in connection with the producer-gas end of the proposed project.

This illustration is given to show that, despite the many assertions to the contrary, very little is yet known about the

application of producer gas outside of a few industries where it has been used for years. Its use, therefore, is more or less of an experiment and the people backing such projects should be made to realize fully the conditions as they actually exist. If this is not done, disappointment and trouble are very likely to follow.

SKILFUL OPERATION ESSENTIAL

Satisfactory gas cannot be made by purely mechanical means. In fact, a very high degree of skill is required in the successful operation of a gas-producer plant, this being especially true in the relatively small plants where only one or two producers are in operation at a time. Uniform results call for uniform gas, and uniform gas can only be produced by the exercise of skill and everlasting vigilance backed by a broad experience. Producer gas never will be a real factor in our industries unless it can be used successfully in these relatively small installations. The problems of getting the right kind of men to take charge of these plants and of keeping down the cost of the gas to a reasonable figure are most difficult. Lack of a proper operating organization has been the cause of many failures which could have been made distinct successes with the right men back of them.

MISREPRESENTATION THROUGH LACK OF PRACTICAL EXPERIENCE

Another cause which has contributed to the unpopularity of producer gas is the over-enthusiastic salesman. Most producer projects look good on paper. Through a lack of practical knowledge as to limitations of the application of producer gas, gross exaggerations as to the results to be expected and, in many cases, absolutely ridiculous guarantees have been made. All these things tend to "bad blood" and an important industry has suffered in consequence.

ARTIFICIAL GASES DEFINED

In order to have clearly in mind the distinguishing characteristics of producer gas, there will be presented, in outline, the different kinds of commercial gases most frequently used.

Natural Gas.—Made by secret processes of Nature; composed largely of methane; and usually runs from 1,000 to 1,100 B.t.u. per cubic foot.

Oil Gas.—Made by bringing oil in contact with heated surfaces. The resulting constituents and B.t.u. vary through a wide range, depending on the oil and the temperature of the heated surfaces.

Coal Gas.—Made by the destructive distillation of soft coal in externally heated retorts with the exclusion of air. The resulting coke is withdrawn at intervals and the retorts are recharged with coal. Coal gas and carbureted water gas are the gases most generally made and distributed for domestic use; they have a calorific power of approximately 600 B.t.u. per cubic foot.

Coke Oven Gas.—This gas is a by-product from the manufacture of coke. It runs somewhat lower than coal gas in B.t.u., but, in general, may be considered as practically the same. Theoretically, the process of manufacture is the same as for coal gas, the practical difference being in the size and shape of the retorts, and the length of time the coal remains in the retorts.

Water Gas or Blue Gas.—Made by the decomposition of steam coming in contact with incandescent carbon, the resulting gas being largely a mixture of hydrogen and carbon monoxide. Coke or anthracite coal is the fuel most commonly used; but bituminous coal is sometimes used, especially in making carbureted water gas, when coke or anthracite is not available. This is an intermittent process, as the fuel must be blasted at frequent intervals with air to bring it back to incandescence.

Carbureted Water Gas.—This is a mixture of water gas and oil gas, and is frequently mixed with coal gas and distributed for domestic use.

Producer Gas.—One pound of carbon, when completely burned to carbon dioxide (CO_2), liberates 14,647 B.t.u., or the total heat energy it contains. It can also be burned to carbon monoxide (CO), 4,383 B.t.u. being given up in the combustion to CO, leaving 10,264 B.t.u. in the resulting 29.82 cu. ft. of CO gas. The commercial gas resulting from this incomplete combustion of carbonaceous material is called producer gas. All the combustible matter of the fuel is consumed. The coke, instead of remaining as a by-product, as in the coal gas process, is utilized in making the gas.

GAS PRODUCER REACTIONS*

The producer gas process of making a combustible gas was discovered in 1832 by Achilles Christian Wilhelm Friedrich von Faber du Faur, Director of the Wurtemberg Government Iron Works at Wasseralfingen, Germany. Many other names have since been given to this gas, such as "Dawson gas," "Mond gas," "Riche gas," "Siemens gas," etc., usually after the men who invented improved methods for its manufacture; but fundamentally the processes are all the same and have for their basis the incomplete combustion of the carbon in the fuel.

*For further information on this subject, see DAWSON and LARTER'S "Producer Gas," 4th ed., 1920.

In order that there may be had a clear conception of how these reactions take place, there are shown in Fig. 281 the various zones as they occur, theoretically, in the body of a simple gas producer. Fuel is charged into the top of the gas producer through the feeding hopper. A limited quantity of air, carrying a predetermined percentage of moisture, is blown into the bottom through

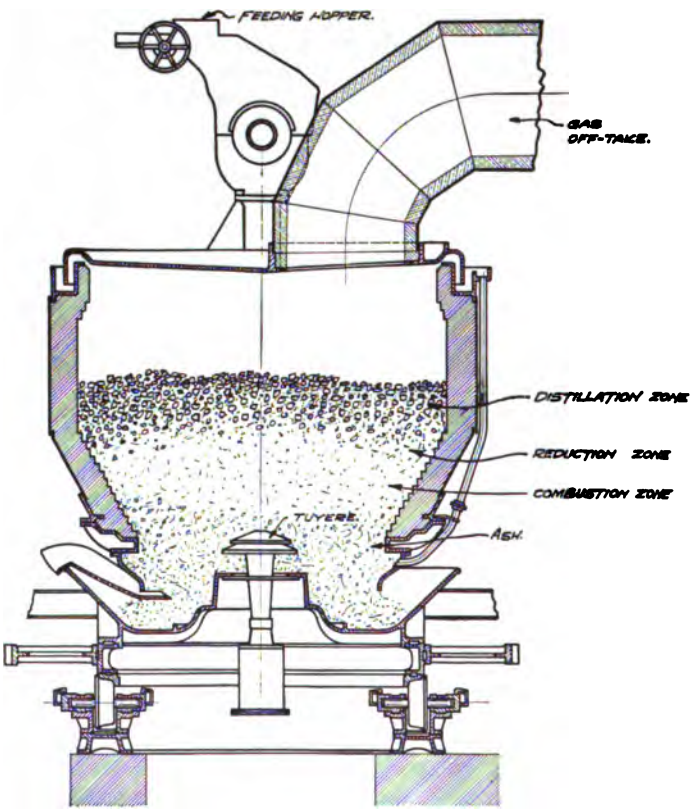


FIG. 281.—Cross-section of a gas-producer.

the tuyere. A layer of ash usually is maintained over the tuyere to prevent its being burned and to distribute the blast uniformly throughout the fuel bed. By restricting the quantity of air to the producer, incomplete combustion takes place in the "combustion zone," as shown. In practice, carbon dioxide is always made along with the carbon monoxide in the combustion

zone and heat is liberated in accordance with the data given above.

The carbon dioxide, which is a non-combustible gas, can be reduced to carbon monoxide, a gas having 340 B.t.u. per cubic foot, by bringing the carbon dioxide in contact with incandescent carbon:

$$CO_2 + C + \text{heat} = 2CO \text{ (endothermic reaction).}$$

In practice, this is brought about by allowing the gases formed in the combustion zone to pass up through the fuel which has been raised to incandescence immediately above the combustion zone.

The second section of the producer, wherein these reactions take place, is called the "reduction zone." It will be noted that two important things occur in this zone: (1) carbon dioxide is reduced to carbon monoxide at the expense of the solid fuel in this part of the producer; and (2) the amount of heat stored in the carbon monoxide thus formed (340 B.t.u. per cubic foot) is taken from the sensible heat of the fuel bed at this point, which results in a reduction of the temperature of the fuel bed in exact proportion to the amount of heat so removed. The reduction zone must be maintained at above 1,600°F., since the reaction mentioned does not take place satisfactorily at lower temperatures.

The third, or top, zone is the preheating or "distillation zone," in which the volatile matter of the fuel is driven off by the heat of the gases passing through it from below.

Atmospheric nitrogen carried into the producer in the blast, plays no part in the gas producer reactions. Moreover, it has no part in the combustion reactions which take place when the combustible gases with which it is mixed are ultimately burned. Since nitrogen is by volume approximately one-half of the total volume of producer gas, it is easy to understand why producer gas has such a low heat value per cubic foot; also why the thermal efficiency of furnaces fired by cold producer gas is so low, unless recuperation or regeneration is used, as will be discussed later.

WATER VAPOR

Water vapor, or steam, is not theoretically necessary in the production of producer gas, but practically it is essential to reduce the temperature of the combustion zone. Too high a

temperature at this point will fuse the ash and result in excessive clinkering, which interferes with the continuous operation of the producer. When steam comes in contact with incandescent carbon, it is decomposed, and a mixture of carbon monoxide and hydrogen is evolved:

$$C + H_2O = CO + H_2.$$

This is an endothermic reaction, exactly the same amount of heat being taken from the fuel bed as can be recovered later when this carbon monoxide and hydrogen are burned with the other constituents of the gas. No possible use of steam can cause an increase of heat in the producer. The heat of combustion of the gas can only approach, but never exceed, the heat contained in the fuel as charged. It naturally follows that the use of steam enriches the gas to the extent of the hydrogen made by utilizing the surplus heat of the producer. Also, the heat taken from the fuel bed, when the water vapor is converted to hydrogen, reduces the temperature of the gases leaving the producer. This is especially desirable when the gases are to be cooled before using, for no practical means has been developed up to date for recovering the sensible heat of the gas after leaving the producer when operating on soft coal.

From this consideration it will be seen that steam or water vapor is very important in the practical operation of a gas producer. No general rule can be laid down for the proper quantity of steam to be used, this varying with the coal, the design of the gas producer, and the purpose for which the gas is to be used. The proper proportion usually is found to be somewhere between one-quarter and three-eighths of a pound of steam for each pound of coal charged.

Carbon dioxide may also be used in place of steam with the blast, since the endothermic reaction which results in reducing the carbon dioxide to carbon monoxide in the combustion zone has the same effect in controlling the temperature as the reduction of water to hydrogen and carbon monoxide. It also has the same effect in enriching the gas at the expense of the surplus heat of the combustion zone. In practice, however, it usually is found much easier to use water vapor; for economically usable carbon dioxide generally contains a large percentage of nitrogen, which is inactive and only serves to further dilute the gas.

GAS PRODUCERS CLASSIFIED

All gas producers can be grouped into two classes on the basis of the physical condition of the gas evolved. Class I includes all types of updraft producers wherein no attempt is made to remove the volatile matter, tar, soot, etc., from the gas as a part of the gas-making process. Class II embraces all types of producers which are designed to free the gas from tarry matter, soot, etc., by passing the volatile constituents through the incandescent fuel bed as a part of the gas-making process. The producers of Class II are worked out on the theory that the volatile matter, on coming in contact with the incandescent carbon, is pyrolyzed into fixed gases without the formation of free carbon, if the proper control of the blast is maintained.

PRODUCERS OF CLASS I

Figure 281 (see the description accompanying it on page 918) is a typical illustration of the producers of Class I.

PRODUCERS OF CLASS II

Three general types or methods of approaching the problem are found in Class II: the downdraft producer, the double-zone producer, and the series producer.

Downdraft Producer.—The downdraft producer is diagrammatically illustrated in Fig. 282. In this type, coal is charged into the top of the producer, as in the simple producer, but the air and moisture are also introduced in the top. The combustion zone may be thought of as between the distillation zone and the reduction zone. The gas offtake is at the bottom of the producer, making it necessary for all the distilled gas to pass down through the entire depth of the fuel bed before reaching the exit. With this arrangement, all the volatile matter from the distillation zone is drawn through the combustion zone and on down through the reduction zone, theoretically bringing about the most intimate contact between the tar-laden gases and the incandescent fuel bed.

Two inherent difficulties prevent this type of machine from approaching the ideal: the rate of gasification is low and the carbon in the ash is high. The latter would follow naturally, for the coke below the combustion zone is moving in the same

direction as the gas and is surrounded by a reducing atmosphere of increasing intensity. Compare this with the simple updraft producer, wherein the fresh incoming air first meets the hot ashes and any unconsumed carbon coming from the combustion zone. The simple producer is obviously the ideal arrangement for reducing the carbon content of the ash to the minimum.

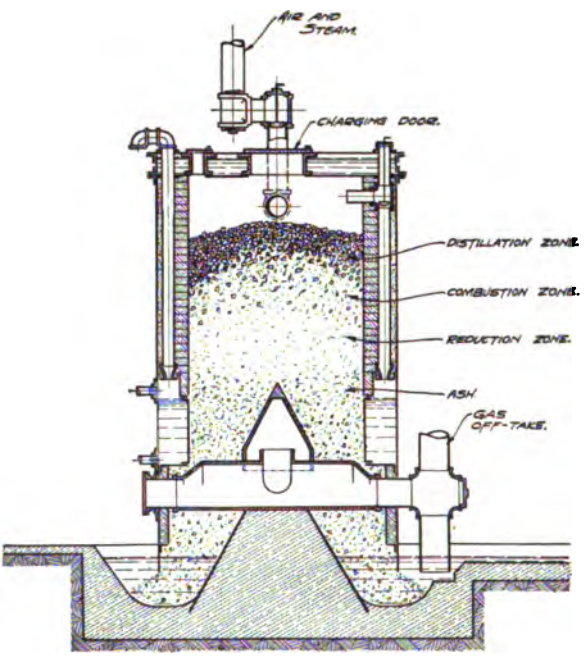


FIG. 282.—Cross-section of a gas-generator, Akerlund system.

Double-zone Producer.—The double-zone producer, shown in diagram in Fig. 283, was designed to overcome the defects of both the updraft and downdraft types and at the same time not sacrifice their advantages. In effect, it is simply a downdraft producer set on top of an updraft producer, with the gas taken off midway between the two. Coal is charged in the top exactly as in the downdraft producer; but the coke formed immediately below the combustion zone is not completely consumed, passing down through the producer and discharging into the top of the simple updraft producer below. The lower part of the machine then functions as a simple updraft producer gasifying coke. The air and steam blown into the bottom complete the reduction

of the coke to gas, and the air and steam blown into the top maintain standard downdraft producer conditions in the upper half. Since the lower producer takes care of all carbon coming down with the ash from the upper producer, coal can be put through the upper producer much more rapidly than is possible with the simple downdraft machine, without an excessive loss of carbon in the ash.

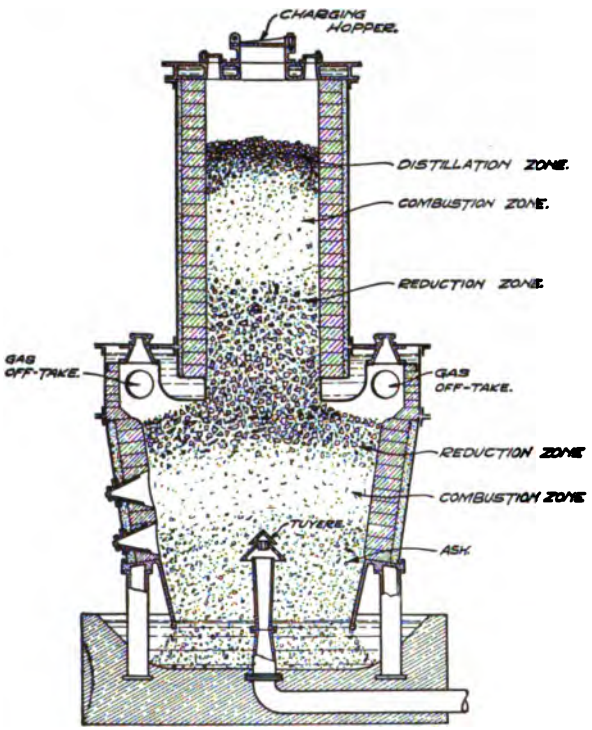


FIG. 283.—Cross-section of a gas producer, double zone type.

On paper, the double-zone producer is the nearest approach to the ideal that has yet been developed, inasmuch as it accomplishes all that can be accomplished with either the updraft or the downdraft machines. Then, too, it eliminates the objections to these types without sacrificing the advantages. The double-zone producer is used quite extensively in Europe and enormous sums of money have been spent to develop it in this country. Several commercial installations have been made, but the results obtained so far do not indicate that this type of producer has been as

successful as it seems to have been abroad: in plain words, the double-zone producer has not been a commercial success in this country up to date.

Series Producers.—The third method of attacking this problem, which has been worked out in a great variety of ways, is to operate two or more producers in series. Each machine is so connected that it can be run alternately updraft and downdraft and the sequence of the series changed. A machine running downdraft is put last in the series, so that all the gas from the machine, or machines, before it passes through the incandescent fuel bed for final fixing of the tar. In some of the arrangements of series producers, water gas cycles are introduced, which help to keep the fuel bed in condition and at the same time enrich the gas.

DETARRING OF THE PRODUCER

The practicability of attempting to design a producer for fixing the hydrocarbons as a part of the gas producer operation is very doubtful. The results obtained in practice under commercial conditions over a number of years offer the best indication, and from this standpoint the following conclusions have been reached.

Gas producers in which the fixing of the hydrocarbon vapors is seriously attempted, must be more elaborate in design and construction than producers of Class I. This calls for more skill in their operation, as well as a greater initial investment per pound of coal gasified. Furthermore, the amount of cleaning apparatus required cannot be reduced appreciably, as the gas always carries a small quantity of tarry matter. At times when the producer is not working right, all the cleaning equipment is required and with the best of operation this will occur. The opinions of experts strongly incline to the view that the complete fixing of the hydrocarbon vapors within the producer is not physically possible and that much of the so-called "fixing" is really a burning of the tar to carbon dioxide. In view of these considerations, it is not surprising to find that the tendency is more and more to utilize the gas-producer process in its simplest form. The most widely used producers today are of the simple updraft type. The expensive mechanical attachments are for decreasing the manual labor and increasing the rate of gasification, but do not in any way complicate the gas-making reactions. This is the present state of the art, but it has by no means been

shown definitely that some scheme cannot be evolved that will result in completely detarring the gas within the gas producer.

BLASTING BY SUCTION AND PRESSURE

The method of introducing air into the producer sometimes is used as a basis for classifying producers. Where air is forced into the producer under pressure, it is classed as a pressure producer, and as a suction producer where the air is drawn into the producer and through the fuel bed by some type of blower or exhauster. In power installations of the suction type, air is drawn into the producer by the suction stroke of the engine. Both the suction and pressure principles have been applied to all the types of producers so far discussed.

MECHANICAL IMPROVEMENTS

Great progress has been made in eliminating the hard labor of charging, poking and removing ashes. Mechanical charging machines tend to distribute the fuel over the fuel bed evenly, which results in a much more uniform fuel bed and consequently a more uniform and better grade of gas. Ash plows, for mechanically removing the ash, tend to bring the fuel bed down evenly all over the producer. Mechanical pokers, stirrer bars, levelers, and agitators have been brought out to keep the fuel bed in uniform condition throughout and to increase the rate of gasification per square foot of producer area.

METHOD OF AGITATING FUEL BED

It is interesting to note that there are on the market today three types of mechanically operated producers of the updraft type, representing three distinct theories as to how the fuel bed should be handled in a producer running on bituminous coal.

According to one view, the fuel bed of the producer should be stirred vigorously and continuously, thus resulting in a much more rapid rate of gasification and in a richer and more uniform gas. Producers designed and built in strict accordance with these ideas are operating successfully and actually getting the results which, it is claimed, should naturally follow this method of poking.

Another theory is that rapid gasification and good gas can only result from very moderate poking, that excessive poking

can only decrease, rather than increase, the rate of gasification, and that non-uniform gas and high carbon dioxide are sure to result. Plant after plant can be inspected where producers have been built on this principle, and the results are apparently all that is claimed for them.

Still another theory is that no mechanical poking at all should be done, all that is necessary being to prevent the formation of channels and blow holes in the fuel bed. This is accomplished by dragging over or through the distillation zone a leveler, or agitator, to maintain the desired condition. The reduction zone and combustion zone are not disturbed, the agitation taking place in the upper part of the fuel bed, or distillation zone, only. Like the other methods, producers designed and built on this theory are in successful operation, gasifying their rated capacity of coal and delivering a good uniform gas.

In addition to these three opposing theories as to the proper method of agitating the fuel bed of a gas producer, the simple hand-poked producer must be kept in mind. It has been indicated that just as good gas can be made in this simple machine, with no mechanical agitation of any kind, as can be made in the most elaborate mechanical producer. However, much more labor is required in the operation.

There are also on the market today producers which work more on the principle of the mechanical stoker for steam-boiler firing. Coal is fed over an inclined grate and the fuel bed is agitated either intermittently or continuously by moving these grates, the theory being that this agitation will prevent the formation of channels and blow holes and that the coal will work down uniformly over the fuel bed. A fairly deep fuel bed is carried and no effort is made to get a high rate of gasification per square foot of grate area. When all these conditions are realized, the result is a rich gas carrying a relatively fluid tar.

These observations seem to verify the opinion that the two most important things about a gas producer are *coal* and *the man running it.* The opposing theories respecting agitation are correct or incorrect, depending upon the conditions surrounding the operation. There is no question but that the kind of coal used has a great deal to do with the way the producer operates and then the physical condition of the coal is important. Generally speaking, screened coal crushed to nut size gives the best results. Most producers are designed to run on all sizes of

coal below 3 in., including slack; but in practice they all work better on prepared coal. The fusing temperature of the ash and the percentage of ash in the coal are very important considerations in connection with producer operation.

UNIVERSAL PRODUCER IMPRACTICABLE

It is impossible to design a producer that will operate best under all conditions. The producer manufacturer, for his own good, should restrict his sales to those conditions where he has found by actual experience that his particular design is most suitable. Since, unfortunately, this is not always done, the buyer, for his own protection, should have a thorough investigation made of all the conditions under which his proposed plant will operate and then select the producer which is best suited for these particular conditions.

BUILT-IN PRODUCER

A producer may be built into and form a part of the setting for other apparatus. This cuts down the radiation loss and eliminates the necessity for long flues and makes a very compact installation. It has the objection of having certain units tied up to certain producers. When either is out for repairs, the other must be idle. Outside producers connected to a common flue, from which the gas is carried to the various points of consumption, tend to result in a more uniform gas and make the producer plant independent of the individual units which it serves.

MECHANICAL CHARGING

Many ingenious schemes have been evolved for eliminating the hand labor of gas-producer operation and at the same time getting better and more uniform results. As an illustration, consider the evolution of the automatic feed now commonly used.

The ideal condition for charging would be to have a steady rain of fuel over the entire fuel bed. In practice, of course, such a condition can only be approached. The simplest charging device is a bell hopper placed in the center of the top of the producer, the hopper being intermittently filled and the fuel dropped into the producer as required. The fuel then is spread as well as possible through poke holes with poking bars. As an improvement over this scheme, a rotating charging hopper was devised which spread the coal over the fuel bed uniformly as it revolved.

With the introduction of the revolving body producer, there has been evolved a mechanical charging device attached to the stationary top which, at frequent intervals, drops small charges of fuel on to the fuel bed as it revolves below. Two such charging devices on a producer give near enough approach to the ideal conditions of charging to satisfy all ordinary purposes.

Also deserving of attention are the various schemes which have been worked out to bring as far as possible the volatile matter distilled from the fuel into intimate contact with the incandescent fuel bed of the producer; that is, to bring about the detarring action aimed at in producers of Class II. This is accomplished by extending a magazine from the charging hopper into the producer, just down to the level of the fuel bed. When this is filled with coal, the sensible heat from the fuel bed of the producer tends to distil off the volatile matter as the coal works down into the fuel bed. It is necessary for the volatile matter, gas, etc., evolved in this retort, or magazine, to pass through the incandescent fuel bed before it can reach the offtake. This scheme has been worked out in many different ways. Some designers have made the retort of refractory material and others of cast iron. Water-cooled retort cast-iron magazines have been used on producers of the revolving type.

WATER COOLING

Producers of the revolving body type usually are water-sealed between the upper and lower stationary sections and the revolving body. On some types, the top of the producer is also water-cooled. Where mechanical stirring bars are used, these, of course, must also be water-cooled. In the most approved design of mechanical feeding hopper, the moving parts next to the producer are water-cooled.

Some makes of producers are built with no firebrick lining, the entire shell being water-cooled. In many designs, the bosh only is water-cooled, the balance of the shell being lined with firebrick. A careful investigation of the water should be made before installing a producer with a water-cooled shell, for serious trouble may result from the formation of scale.

In the simple hand-operated producers, water-cooling is not necessary. In many of the simple hand-operated producers, evaporators are placed in the top of the producer to utilize a part of the sensible heat of the gas in raising the necessary steam

or vapor for mixing with the blast; and this makes it unnecessary to have an auxiliary steam plant in connection with the producer. Where the investment in the mechanical producer is warranted, the rate at which gasification must be maintained renders this scheme of saturating the blast impracticable; under these conditions, auxiliary boiler plants must be relied on for the blast saturation.

WET- AND DRY-BOTTOM PRODUCERS

Producers are also classified as wet- and dry-bottom. Dry-bottom producers utilize some form of grate-bar for carrying the fuel bed. The ashes are removed from the pit below the grates in a manner very similar to boiler furnace practice. Wet-bottom producers have no grates. The burden of the fuel bed is carried by the ashes, which rest in an ash pan filled with water, directly under the producer. The producer shell is carried down and seals into this water. The ash pan is enough larger than the shell of the producer that the ashes can be removed through the water-seal around the producer shell (see Figs. 281 and 282).

ASH AND CLINKER REMOVAL

Practically nothing in a mechanical way can be done to facilitate clinker and ash removal on the simple stationary producers. However, the rotary types present possibilities. The tuyeres can be located eccentrically or provided with rough surfaces, so that large clinkers are crushed as the machine revolves; but the machine must be designed to crush the clinkers or the revolving feature only exaggerates the trouble. Ash plows have been developed which operate very successfully in removing the ashes uniformly from all sides of the producer.

The Taylor producer was one of the earliest forms of mechanical producers brought out in this country. It carried a revolving ash table which automatically plowed the ash from the body of the producer. Practically all modern types of mechanical producers have some form of clinker crusher and mechanical ash discharge.

SUMMARY OF MECHANICAL IMPROVEMENTS

The net results to date of the many mechanical improvements and labor-saving devices which have been developed in connection with the gas producer, may be summed up as follows:

The rate of gasification per square foot of grate area has been increased approximately 100 per cent.

The strenuous labor of poking and removing ash, although not eliminated, has been reduced greatly.

With the mechanical producer it is easier to keep more nearly uniform conditions throughout the producer, which results in a more uniform gas of somewhat higher calorific power.

The cost of a gas producer embodying all these improvements is necessarily much greater than the cost of a simple producer depending on hand operation.

The demands of the service are the only factors which can decide the most economical type for any particular installation.

FREAK PRODUCERS

If all the information concerning the producers which have been built and tried out could be tabulated and analyzed, and the reasons for discontinuing the work carefully brought out, it would probably be one of the most valuable treatises on the subject of the gas producer which could be published. Unfortunately, most specialists prefer to talk of their successes rather than their failures, with the result that mistakes are repeated over and over again.

The following brief references to some of the special work which has come under the author's personal attention, or supervision, may be interesting.

A great deal of time, money and energy was spent in developing an underfeed producer, and many schemes for getting the coal into the producer were tried out thoroughly. In one procedure, the coal was carried into the bottom of the producer with a spiral screw. In another scheme, the coal was forced into the bottom of the producer by a piston plunger. Another method of attack was to build the tuyere as a segment of a spiral and feed the coal through the sides of the producer at the bottom: as the spiral revolved, the coal was lifted into the body of the producer. All these producers made gas, but the maintenance charges of the mechanism were very high. It was also demonstrated to the entire satisfaction of all parties concerned that any such methods of feeding coal were of very doubtful success, since the coal became ground to a fine powder before it finally reached the combustion zone, with the result that it was almost impossible to blast through it and absolutely impossible to keep the blast uniform.

Another scheme, devised by the author, for making clean producer gas without cooling and condensing was to take the gas from a standard producer and pass it immediately through a bed of incandescent coke, enough air being admitted to the second vessel containing the coke to maintain incandescence. The carbon dioxide formed by this combustion was again reduced to carbon monoxide in passing with the gas through the incandescent coke. This machine was first built on an experimental scale and

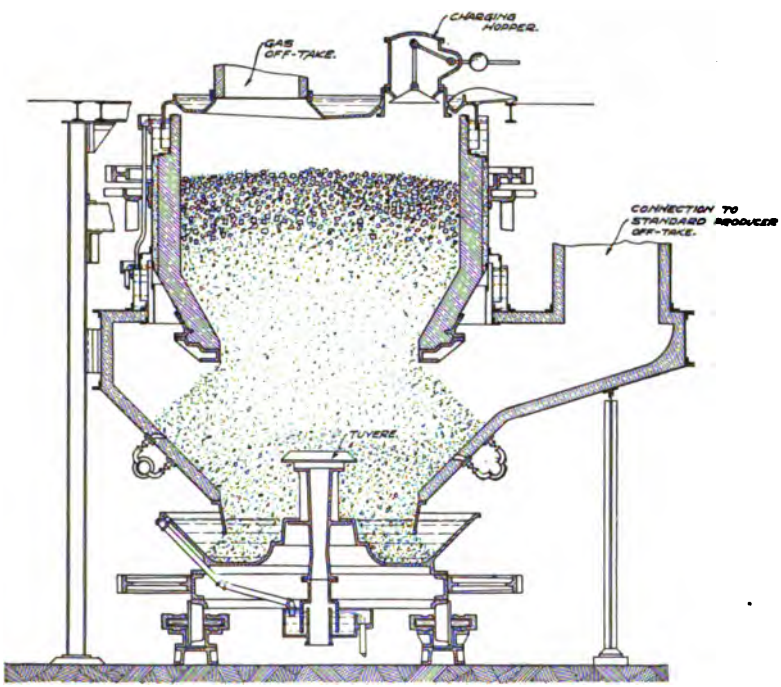


FIG. 284.—Cross-section of a coke detarrer.

proved so successful that it was built with a sufficient capacity to care for all the gas from a modern mechanically operated producer. A sketch of the installation is shown in Fig. 284. After this installation had been in operation for several months, it was found that gas of a uniform quality could be produced which carried no more tar than gas from coke when gasified in the simple producer. It was impossible, however, to operate the coke section of this apparatus without gasifying practically as much coke, pound for pound, as coal. Also, there was the necessity

for constantly keeping the balance between the two machines. An exhauster was required to pull the gas through the coke machine and it had to be so regulated that excessive suction was not thrown on the producer. This method of making gas proved to be entirely feasible; but, after all the advantages and disadvantages were summed up, it was found that a more satisfactory operation and about as cheap gas could be made by simply gasifying coke.

Only the simple schemes in connection with the gasification or burning of fuels seem to survive. *Experience shows that it is an easy thing to design a machine which will save heat, but it is a real accomplishment to design a machine which will save heat and money at the same time.*

FUELS

A very wide range of fuels can be gasified successfully in the gas producer. In fact, almost any kind of carbonaceous material can be converted into producer gas if it does not carry too much water or is not too greatly diluted with non-combustible material. Research has shown that producer gas can be made from wood, tan bark, straw, and garbage; in fact, almost any kind of waste material containing carbon can be gasified in the gas producer. To date, however, it usually has been found in practice to be a losing proposition to gasify these waste materials when a good grade of coal can be obtained at a reasonable cost. The time may come when practically all waste organic materials will be turned into gas; but as long as our natural fuels are so plentiful, and with no restrictions on their extravagant use, there will be no incentive to use these cheaper wastes.

Charcoal.—From the standpoint of simplicity of operation, charcoal is the ideal fuel. It contains but a small amount of tarry matter and is handled easily in the producer. Charcoal can be gasified in the simplest type of gas producer, the moisture for the blast can be raised from the sensible heat of the exit gases, and there is no occasion for any of the mechanical appliances such as pokers, ash plows, etc. The cost of charcoal, however, makes its use practically prohibitive for ordinary industrial operation.

Anthracite.—Anthracite ranks next to charcoal as an ideal gas producer fuel, and it is the fuel generally used in suction power plants. Anthracite contains practically no volatile

matter and can therefore be used in the simplest type of updraft producer. Moreover, mechanical agitation of the fuel bed and mechanical ash removal are not necessary, although the last-mentioned operation is advantageous in reducing the manual labor. The small sizes of anthracite, pea and buckwheat, have been gasified very successfully in some of the mechanical producers, by removing the stirring bars and retaining the other mechanical fixtures.

Coke.—In many respects, coke is a very desirable fuel for gas-producer work. The gas from coke contains a relatively low

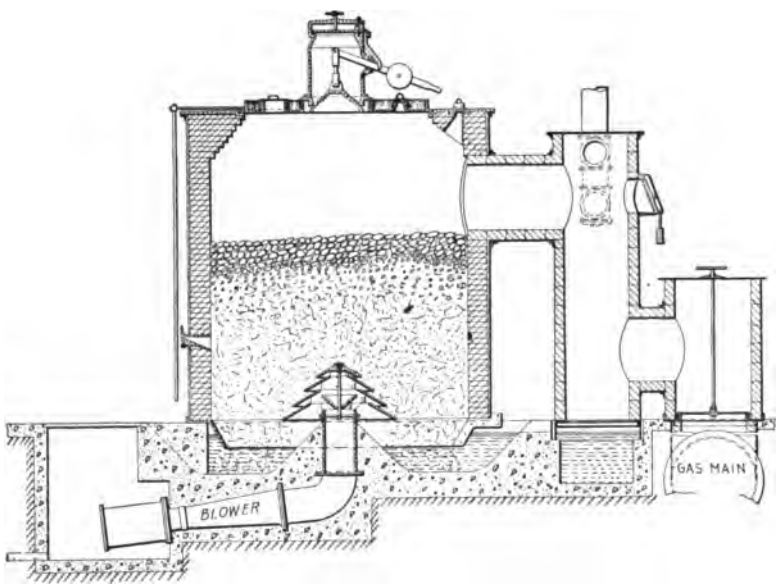


FIG. 285.—Simple updraft hand-poked gas producer and hot-gas offtake and connections.

percentage of volatile matter, depending on how completely the coking process is carried out, and the percentage of tarry matter in gas made from coke is much lower than that from bituminous coals.* Coke can therefore be gasified in the simple type of updraft producers; but it must be carefully noted that the tarry matter which results from the gasification of coke, although small in quantity, is very difficult to handle, being exceedingly viscous and worse than other tars in filling up pipe lines.

*Coke from gashouse retorts tends to run very much higher in volatile matter than metallurgical coke from by-product coke ovens.

Coke of all sizes can be gasified, but the sizes ranging between nut and pea seem to give the highest rate of gasification per square foot of grate area. The sizes including pea and below can be successfully gasified, although at a decreasing rate of gasification.

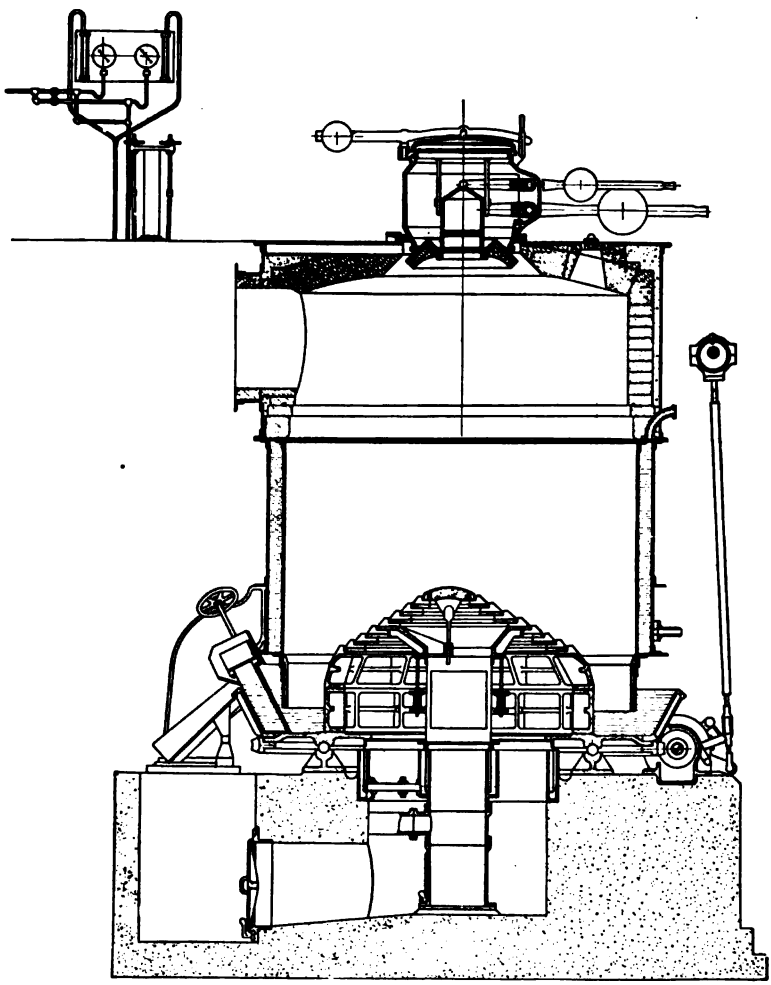


FIG. 286.—Kerperly gas producer for small coke (revolving grate, automatic ash discharge).

Then, too, the smaller sizes of coke carry a higher percentage of volatile matter than the larger sizes. As an illustration of this point, observations taken on a large commercial installation using

coke disclosed the fact that, when pea coke was used, the gas carried from 3 to 4 per cent more volatile matter than when nut coke from the same ovens was used. It is interesting to note that this difference of between 3 and 4 per cent in the tarry matter carried by the gas made the operation with pea coke impossible with the equipment as installed. The burners wherein this gas was used became plugged up so frequently that it was found more economical to pay the additional cost of the nut coke and eliminate the burner troubles.



FIG. 287.—Two 100-hp. units, anthracite heat, for hardening, tempering, etc., Simonds Canada Saw Company, Montreal, P. Q.

Although coke can be gasified in the simplest form of updraft producer, the best results have been obtained in a producer specially designed for handling coke, especially the small sizes. There seems to be a distinct difference of opinion as to the advisability of mechanical agitation of the fuel bed. In installations of more than one or two producers, mechanical ash removal unquestionably would be warranted.

Owing to the fact that blast-furnace men now generally agree that screened coke will give a greater yield of pig iron per ton than run-of-oven coke, there is a gradual accumulation at many blast-furnaces and coke ovens of the screenings from the furnace coke, a practice which did not occur in the past. These screenings are relatively high in ash and are not suited for use in ordinary domestic heating plants. This, coupled with the fact that the

production of by-product coke throughout the United States has been stimulated by the war almost beyond the point where it can



FIG. 288.—Two 100-hp. anthracite producers, Simonds Canada Saw Company, Montreal, P. Q.

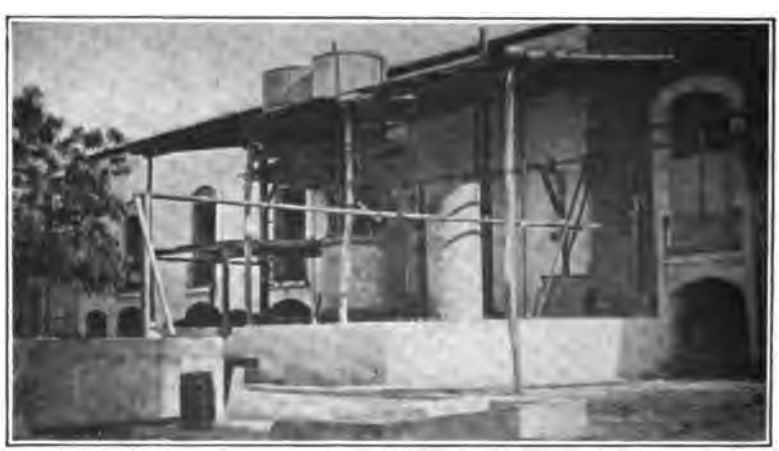


FIG. 289.—One 150-hp. type "B," fuel, wood, cocoanut shells, etc., at Hda Timul, Yucatan, Mexico.

be absorbed by the ordinary commercial user, would make it seem that coke, especially of the smaller sizes, should play a more important part as a producer fuel in the future.

A typical analysis of gas made from nut coke is given as follows:

This analysis is the average for 1 month.

CO_2	6.8 per cent
O_2	0.1 per cent
CO	25.8 per cent
H_2	12.4 per cent
CH_4	0.8 per cent
N_2	54.1 per cent

Calorific value:

The value figured from the above analysis is 132 gross B.t.u. per cubic foot, or 125 net B.t.u.

Gas produced:

From 135,000 to 140,000 cu. ft. of gas were produced per ton of coke.

These results were obtained on gas made in a modern mechanical type of producer, with automatic charging and poking mechanism and mechanical ash removal. The rate of gasification ordinarily maintained was 20 lbs. of coke per hour per square foot of producer area.

Peat.—Some work has been done in this country on the gasification of peat in gas producers. While it has been accomplished successfully, the probabilities are that it never will be commercially possible to ship peat any great distance for this purpose. Peat normally carries a very high percentage of water which must be removed before it can be gasified successfully.

Lignite.—The work which has been done to date on the gasification of lignite looks promising. If the tremendous quantity of lignite now available in the Middle Western States could be turned into useful fuel, it would add greatly to the fuel resources of this country.

Lignite has been gasified successfully in producers of both the updraft and downdraft type. Its greatest drawbacks as a fuel are that it cannot be hauled commercially any great distance because of the large amount of water it contains and that, when it is exposed to the air, it slacks very rapidly. Tests have shown that producer gas from lignite carries a very high percentage of ammonia. The subject of ammonia recovery in connection with producer gas is discussed on page 969.

Bituminous Coal.—Bituminous coal is a broad term, including everything between anthracite and lignite, coking coals, caking coals, and coals that do neither, coals that vary all the way from 4 to 40 per cent ash, coals that give ash of widely varying fusing

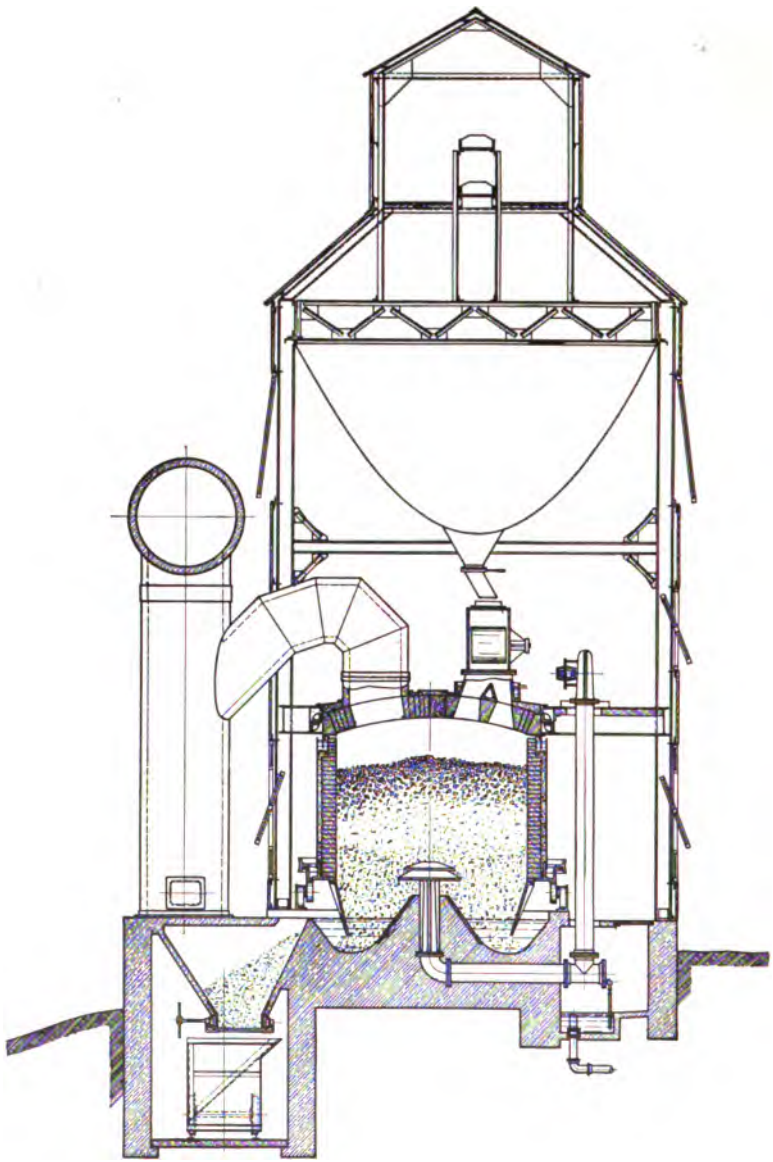


FIG. 291.—Cross-section of a simple hot producer-gas installation.

Hot Raw Gas.—The advantages of the first scheme, that is, of using the gas hot, is that the sensible heat of the gas is not lost. Also, the heating value of the gas is increased to the extent of the tarry matter carried into the combustion chamber. The cost of the gas per B.t.u. is less, and the gas plant is much more simple and less expensive.

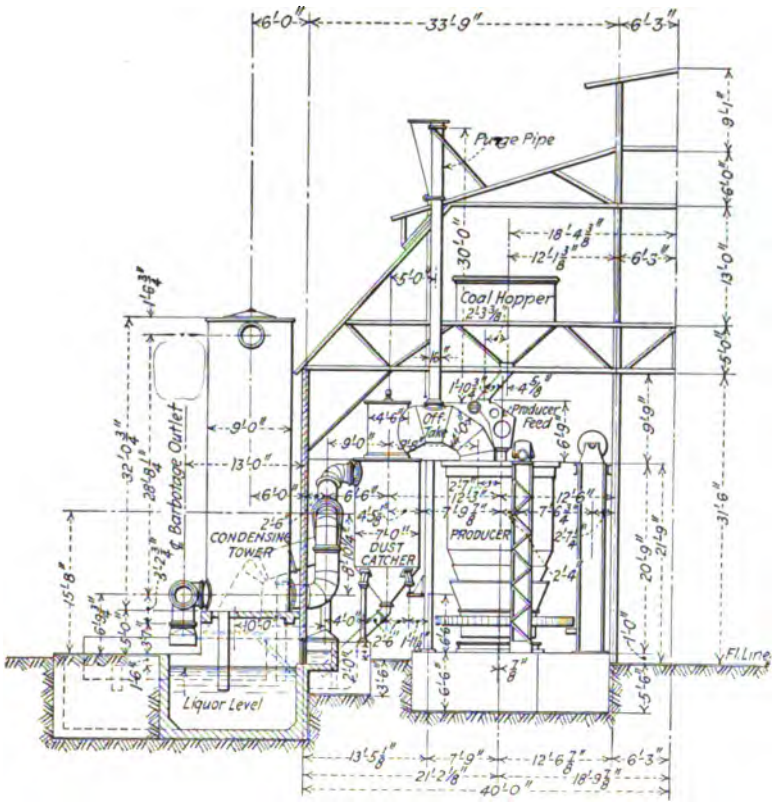


FIG. 292.—Cross-section of producer gas plant, showing producers located in building, with other apparatus and condensing towers outdoors. This plant is gasifying small coke. The gas is cooled and cleaned.

Where the gas is carried long distances, the cost of flues becomes prohibitive. Hot gas flues are built both above ground and underground. Above-ground flues usually are made of $\frac{3}{16}$-in. steel plate lined with firebrick. Underground flues generally are made of brick, sometimes of concrete, but always are lined with firebrick. The best flue construction provides for a layer of heat

insulating material outside the firebrick. Typical cross-sections of both above-ground and underground flues are shown in Figs. 290 and 291. The heat insulation is necessary, first, to prevent the loss of the sensible heat of the gas, and, second, to retard the deposition of the hydrocarbons from the gas. Some of the hydrocarbon vapors condense at relatively high temperatures, and, as the temperature of the gas falls, the deposition in the flues increases very rapidly. This not only results in a loss of heat actually transmitted to the furnace, but makes it necessary to clean out the flues at frequent intervals by a process called "burning out."

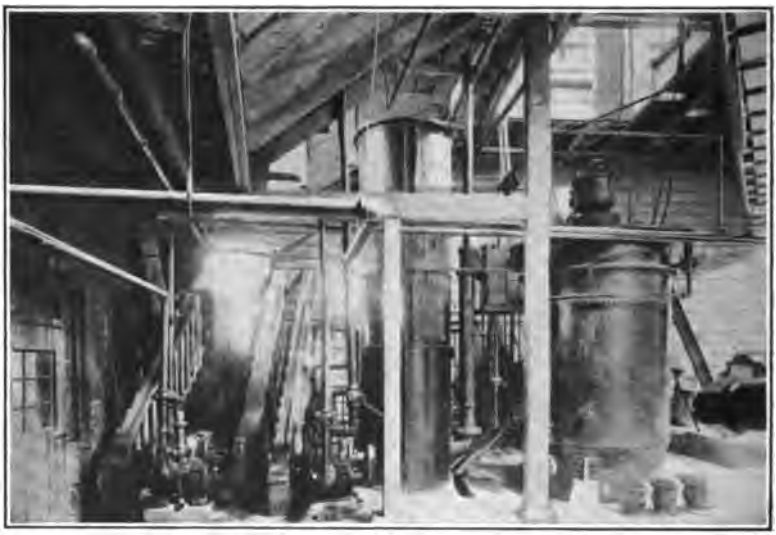


FIG. 293.—Seventy-five hp. anthracite heat, for annealing, tempering, hardening, etc. (*New York Knife Company, Walden, N. Y.*)

In laying out hot-gas flues, provision must be made for cleaning every part of the flue from the producer to the point of consumption, because solid matter begins to deposit from the gas before the gas leaves the producer. A typical cross-section of a simple hot-gas installation, showing overhead flues and cleanouts, is shown in Fig. 292.

The flues at some point must be connected to a stack. When it becomes necessary to "burn out," the stack damper is opened. The stack then furnishes the draft for drawing in the necessary air to maintain combustion of the deposited tarry matter. With

sufficient air, the deposits in the flues can be burned out completely when once ignited. During the period of burning out, the plant is practically shut down, which in some cases amounts to a serious loss. The smoke and soot resulting from this burning-out process are very objectionable, especially in settled districts, and therefore very few cities will permit this practice within the city limits. By using low-volatile fuel, such as hard coal or coke, the difficulties arising from deposits in the flues are practically



FIG. 294.—Three hundred-hp. anthracite, 250-hp. for engine, d. c. to generator, balance of gas used for hardening, annealing, etc. (*Keystone Watch Case Company, Jersey City, N. J.*)

eliminated. This has proved the answer to some rather difficult problems in the past where the somewhat lower calorific power gas resulting from the use of coke was not objectionable.

Clean Cold Gas.—When producer gas is cooled and cleaned, that is, freed from the tarry matter it carries, it can be pumped great distances in relatively small pipes and lends itself to general distribution throughout industrial plants. This is unquestion-

ably a great advantage, but it is to some extent offset by other disadvantages. Where bituminous coal is used, the sensible heat of the gas as it comes from the producer cannot be recovered profitably with any apparatus which has been brought out to date. This loss figures out to approximately 1 per cent for every 100°F. of temperature in the exit gases. To illustrate, if the gas leaves the producer at a temperature of 1,200°F., the loss is approximately 12 per cent.

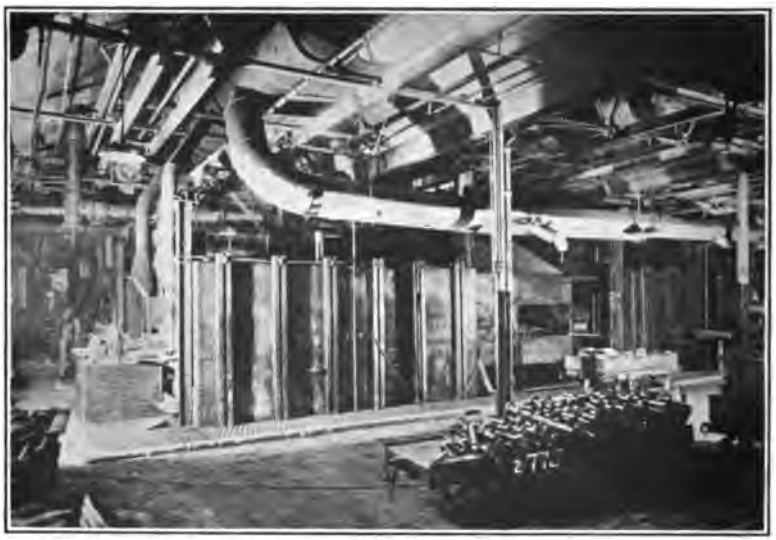


FIG. 295.—Continuous heat treating furnaces fired with producer gas, developed and built by the Steere Engineering Company. These furnaces are of the double regenerator type. Provision is made for mechanically handling the material through the furnaces.

Where high temperatures are required, producer gas can only be used successfully either by putting it under pressure or by a system of recuperation or regeneration of either the gas or air, or both. It is interesting to note that, in many of the installations where hot gas is used, the hot gas, although direct from the producer, is put through regenerators with the same periods of reversal as the air. It has been found in practice that putting the gas through the regenerators gives a more uniform and satisfactory condition in the combustion chamber. This is due, undoubtedly, to the fact that the hydrocarbon vapors carried by the gas are pyrolyzed or "cracked" to fixed gases on

coming in contact with the hot checker-work. The resulting gas then is a homogeneous mixture of producer gas carrying no slow burning hydrocarbons. The regenerators also act as heat reservoirs, keeping the gas at a uniform temperature as it enters the combustion chambers.

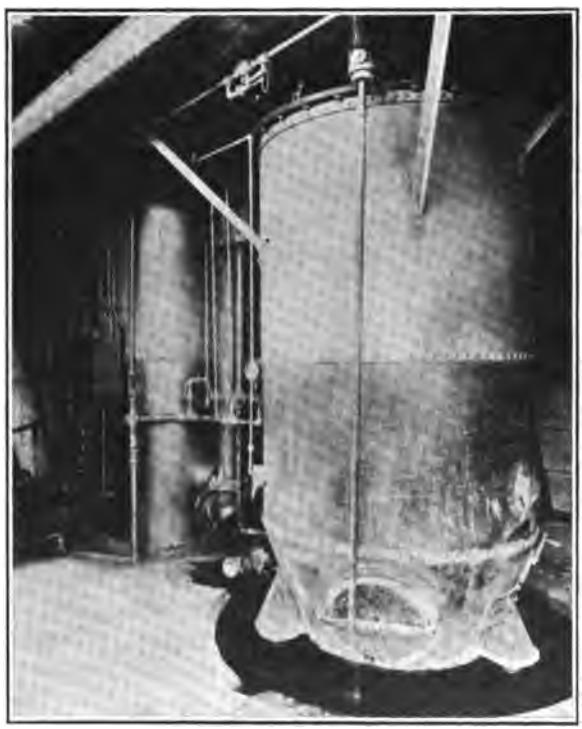


FIG. 296.—Fifty-hp., using anthracite and charcoal, heating enameling ovens, Sociedad Industrial de Cuba, Luyano, Havana, Cuba.

CLEANING GAS FROM LOW VOLATILE FUELS

Before discussing the application of clean cold gas to industrial heating operations, the various methods and problems encountered in the process of cleaning and distributing producer gas will be reviewed.

Producer gas from low volatile fuels, such as anthracite or coke, require a relatively simple cleaning plant. The gas as it comes from the producer usually is led directly into some form of dust catcher. From this it passes into a tower scrubber filled with wooden grids over which water is sprayed.

This not only removes the sensible heat of the gas, but also serves to wash out a large portion of the dust and other impurities which the gas carries. Immediately after the washers comes the exhauster, or gas blower, which takes the gas from the producer and delivers it to the point of consumption.

In large installations, the cooling usually is done in two stages. In small installations, however, single-stage cooling is sufficient. After the exhausters, some form of dry scrubber often is used, such as a bed of shavings or sawdust, or a tower filled with coke. This type of plant is very simple and will work satisfactorily on anthracite and on coke, if the gas is not to be used in small burners or passed through small orifices. Coke contains an appreciable percentage of the very high boiling-point tars. These tars are carried along with the gas in a fine state of subdivision and will not wash out with the ordinary simple washing plant, as described above. If they are to be removed completely, they must be passed through some type of mechanical tar extractor or through the high-tension electrical precipitation process, described later.

A very interesting possibility in connection with the gasification of low volatile fuels, such as anthracite and coke, is the use of a waste-heat boiler immediately after the producers, to recover the sensible heat of the gas. Plants running on coke are now in very successful operation, in which all the steam for operating is raised in the waste-heat boilers. This also helps out the cooling towers, since the gases, on passing through the waste-heat boilers, can be lowered approximately 600°F.

CLEANING GAS FROM HIGH-VOLATILE FUELS

Before discussing the layout of a cleaning and condensing plant for producer gas from bituminous coal, the conditions which surround the formation of the tar and its subsequent physical condition will be considered.

When coal is subjected to heat, the various volatile constituents are expelled in the vapor form. The boiling-points of these vapors vary all the way from around 175°F. to above a red heat, depending on the temperatures at which they have been distilled and the subsequent cracking and recracking resulting from their exposure to the higher temperatures of the distillation chamber. As the gas carrying these vapors cools, the vapors condense out in the form of a fog. These vapors are all more or less soluble

in one another, so that the resulting solution, which may be constantly changing, becomes extremely complex.

The temperature in the combustion zone of the gas producer is higher than the temperature ordinarily found in a closed retort. Moreover, the conditions under which the distillation takes place are entirely different. The result is that producer gas tar is an entirely different product from coal-gas tar made in closed retorts. It carries a much higher percentage of high-boiling-point tars, which makes it much more pitchy. Bottles are not always required for samples of producer gas tar; a tar sample oftentimes can be wrapped in a newspaper.

Large percentages of the volatile constituents of the coal leave the producer offtake as true chemical vapors; that is, they are not condensed, for the temperature at this point is above the temperature at which they vaporize. Those which have condensed at the temperature of the offtake are in an almost molecular state of subdivision. It would be difficult to conceive of matter in more minute particles than these condensed vapors at this temperature. Immediately upon leaving the producer offtake, the gas is showered with water in a preliminary washing until the gas itself is saturated with water vapor. This saturation temperature usually runs under 150°F., depending on the amount of steam used in the blast. Picture what happens when the hot gas at the producer offtake, containing this very complex mixture of condensed and non-condensed vapors, is cooled suddenly to 150°F. The result is that the finely divided condensed vapors which have been carried in the gas at the high temperature and which in this state have been more or less fluid, are chilled to relatively hard particles; also, the cooling is brought about so suddenly that it gives no chance for coalescence and formation of larger globules. The same conditions obtain with the hydrocarbon vapors which have been uncondensed at the temperature of the offtake; in being cooled, suddenly they likewise have no time or opportunity for agglomeration and are found condensed at the lower temperature in the same minute state of subdivision. The gas then, after its preliminary cooling and saturation, contains a tar fog, or mist, made up in part of the most minute particles of condensed tarry matter.

The great difficulty which always has been experienced in cleaning producer gas is directly traceable to the physical condition of the tar fog. Producer gas tar is very much more difficult

to remove from gas than coal-gas tar made in closed retorts. The reason is obvious: coal gas does not come in contact with as high heats at any point in its travel, and therefore does not carry as high a percentage of the higher boiling point tars, or pitch. Then, too, retort tar is the result of dry distillation, while the conditions in a gas producer are entirely different, as has been noted. The more fluid the tar particles, the more readily they coalesce into the larger globules. The old theory of condensing gas was to cool very slowly and not to wash with water in the early stages of condensation. There are theoretical considerations both for and against such practice which are extremely interesting. Practically, however, in a plant of any considerable capacity, the cost of equipment becomes so great that this method is prohibitive. It has been found much more practical to offset the difficulties resulting from rapid condensation by later providing more efficient means for tar extraction.

In the producers of Class II, wherein the hydrocarbon vapors are passed through the incandescent fuel bed for the purpose of removing the tar, experience has shown that, except when in the hands of very skilful operators, either tar or soot, and usually both, are produced. Soot is about as difficult to remove completely from gas as tar, but its effect in pipe lines and the distribution system is not so bad; that is, a plant can be kept running much longer when small quantities of soot are left in the gas than when tar is the contaminant. The worst combination is a mixture of the two. Clean producer gas never will be a complete success in any plant with anything like an elaborate distribution system unless the tar is thoroughly removed from the gas.

PLANT LAYOUT FOR CLEAN PRODUCER GAS

To illustrate the various points of design which are extremely important in connection with condensing and cleaning producer gas, a specific installation will be described. Figure 297 illustrates a plant having a capacity of 15,000,000 cu. ft. of producer gas per 24 hrs., which represents the gasification of 125 tons of bituminous coal per 24 hrs.

The rate of gasification per square foot of producer area depends very largely on the type of producer, but it may be laid down as an invariable rule that the manufacturers' ratings are too high for safe figuring. These ratings are established with

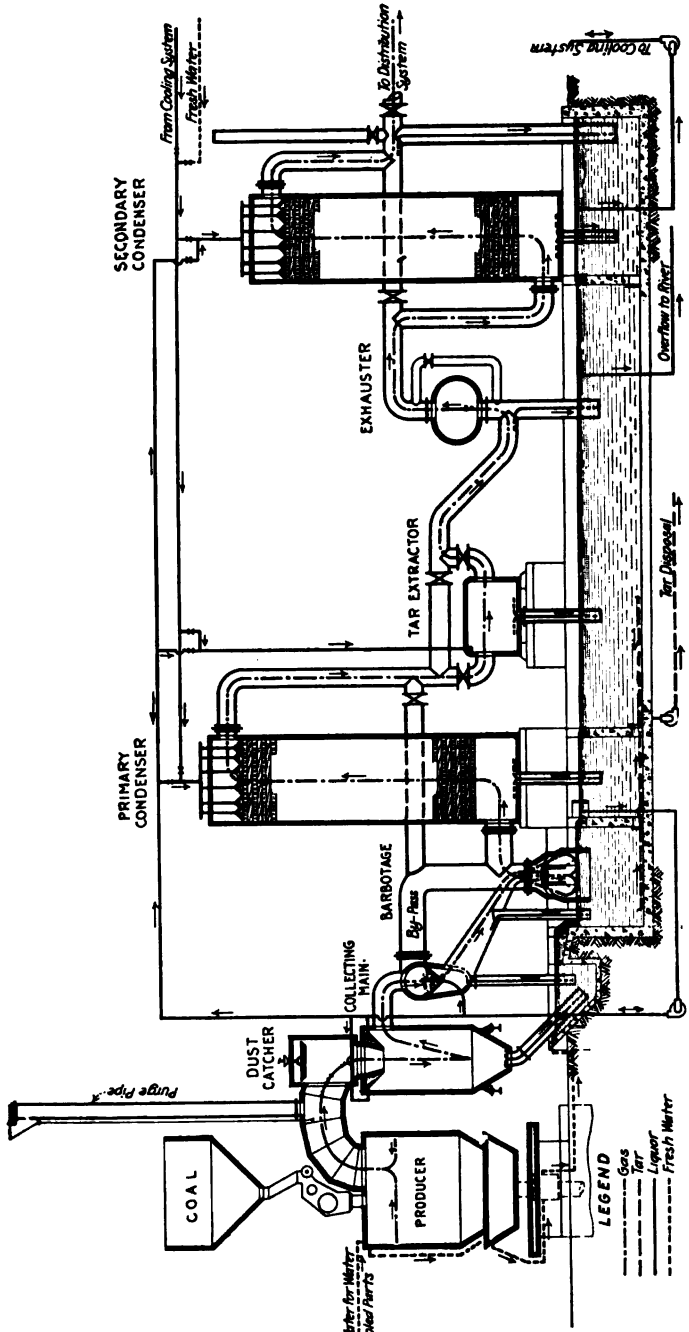


FIG. 297.—Flow sheet for producer gas condensing and cleaning plant. (*Steere Engineering Company, Detroit, Mich.*)

the producers running under the most favorable conditions. In practice, however, favorable conditions are the exception rather than the rule. Gasification rates run from 8 lbs. in the hand-poked producers to 20 lbs. per square foot per hour in the mechanical producers. Higher rates often are attained, but 20 lbs. per square foot per hour, day after day, is very good. If the plants is to be run at full capacity, 24 hrs. per day, that is, carry a high-load factor with no shutdowns at week ends, an extra producer should be provided as a spare.

The coal bunkers should be located over the producers, so that the coal can feed into them by gravity. The coal should be crushed to 3 in. and, where feasible, it should be screened. This can be worked out very nicely when the producer plant is located close to or in the same building with a steam power plant. The screenings from the coal then can be used under the steam boilers and the clean coal can be delivered to the gas producers. Where producers are used with mechanical pokers, stirrer bars, etc., special precautions must be taken in the design of the building and the arrangement of apparatus to give ample room for removing these parts. Stirrer bars have to be replaced in these appliances every 3 to 6 months, sometimes longer, depending a good deal on the type of fuel used.

In the general layout provision should be made for handling the ashes. From a plant of this size, running to capacity, there will be from 15 to 20 tons of ashes per day. This quantity will warrant a fairly complete ash-handling system. If the ashes are wet, there is still more difficulty in handling them by hand and a suitable system becomes all the more necessary.

The gas passes from the producer through the offtake, which should be of ample size, to handle the gas without creating a back pressure on the producer. With the producer gasifying a ton of coal per hour, the offtake should not be less than 4 ft. in outside diameter. The offtake should be firebrick lined up to the point where water is first introduced. It has been found highly desirable immediately after the producer to discharge the gas into a rather large chamber for throwing down the dust and heavy dirt which it carries. This dust catcher either can be run dry, in which case it should be lined with firebrick, or it can be run wet, when the gas is first washed with water.

It is necessary to have some sort of valve as close to the producer offtake as possible, so that any producer can be cut out for

cleaning, repairs, etc., without interfering with the rest of the plant. A design can be worked out whereby a mushroom-type valve is located immediately over the dust catcher. This simply is lowered to the seat when the producer is to be cut out. A purge pipe should be provided between the producer and this first valve; this pipe is necessary for bleeding the gases to the atmosphere when the machine is first put into operation. When started from cold, it usually takes at least 4 hrs. before a producer is making satisfactory gas. During this period, all the gases made are discharged into the purge pipe and the valve connecting the producer with the balance of the system is closed. The purge pipe is also necessary as a relief when the plant is closed down suddenly. The gases which are evolved after the blast is cut off from the producer then are led directly to the atmosphere. The purge pipe must be provided with some type of valve or cap so that it can be closed tightly when the producer is delivering gas into the main system. If this valve is not closed tightly, either air will be drawn in, if the top of the producer is under suction, or gas will be wasted, if it is under pressure. The opening and closing of the purge-pipe valve, or cap, must be controlled from the producer operating floor, and it is important that the mechanical arrangement be worked out nicely, so that it can be manipulated readily. It is the working out of details such as these that makes a plant safe to operate with a minimum loss of gas.

Means must be provided for poking out and cleaning every part of the gas connection between the producer and the point where the gas has become saturated with water vapor. This can be done with properly located poking holes. Tar, soot, dust, etc., start depositing from the gas even before it is out of the gas producer. The hot gas sweeping over the deposits has a distilling action on the volatile matter contained therein. The result is that the deposits become baked to the linings and in many cases can only be removed by direct poking. When the offtake starts to fill up and a back pressure is thrown on the producer, the rate of gasification drops off very rapidly. The same applies to the dust catcher. If it is run hot, means should be provided so that every part of its interior can be reached by long chisel bars and the bottom should be provided with a large dump door through which the dry material can be cleaned out. Various methods have been developed for bringing this about, but the

principal point is to have the dust catcher large enough so that this will not have to be opened up too frequently and to have the doors of such a size that the interior can be cleaned completely. If the dust catcher is sprayed, then the heavy dirt which is thrown out at this point must be washed to a sump. This should be located as close as possible to the dust catcher, preferably directly under it. The bottom of the dust catcher can be sealed in this sump and the dirt hoed out from under the water. The advantage of the wet dust catcher is that it can be cleaned without opening. It will be noted that each individual producer is equipped with its own dust catcher. The dust catchers all discharge into a common collector main. If the gas is sprayed with water in the dust catcher, it should enter the collector main practically saturated with water vapor. If it is not sprayed in the dust catcher, it should become saturated in the collector main. In either case, the collector main should be sprayed heavily with hot recirculated liquor, as will be explained later.

The continuous wetting of the entire inner surfaces of the mains prevents the accumulation of pitch and tar and the resulting stoppages. The bottom of the collector main should have a decided drop, preferably in the direction in which the gas passes, so that the liquor will run with the gas instead of against it. A portion of the heavy tars always comes down in the collector main and is washed along by the hot liquor to the point of discharge. At least one point on the collector main, preferably the point at which the gas is discharged, should be sealed in the "decanter."

A "decanter" is a tank made either of concrete or steel, preferably concrete, into which all the tar and liquor ultimately drain. Every piece of apparatus should be provided with a drain directly into the decanter. Drains are usually the "bugbear" of a producer-gas plant. They are seldom made large enough, but, obviously, the shorter they can be made the better. The decanter, therefore, should be so designed that as much as possible of the gas-plant apparatus shall be placed directly over it, so that the drain drops straight from the apparatus into the decanter. The circulating liquor and tar which are washed along through the collector main, discharge directly into this decanter. The discharge pipe, which should be not less than 16 in. in diameter for this size of plant, is sealed at least a foot below the lowest possible water level of the decanter. The gas

at this point normally will have a temperature of between 140 and 150°F.

The next apparatus should be either a tower equipped with baffles and heavily sprayed or some type of bubbling apparatus which will bring the gas into intimate contact with the washing water. After passing through this apparatus, the gas should be freed fairly of its heaviest tars. If bled into the air at this point, it should have a rich yellow or creamy appearance: this color is due entirely to the fine tar fog which it still carries and which is so difficult to remove. A combination of the bub-

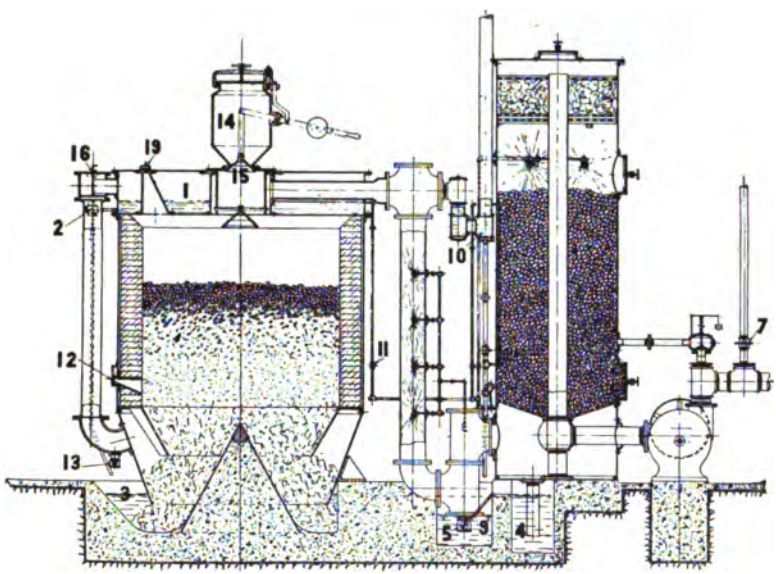


FIG. 298.—Akerlund type "A" gas producer.

bling apparatus and the tower can be used profitably where there is a high percentage of heavy pitch. With this combination, the tower, which should follow the bubbling apparatus, can be sprayed with cooled water. The temperature of the gas then can be reduced in the tower to approximately 115°F.

Following in the line of apparatus is some type of tar extractor, or the exhauster. If there is a high differential pressure over the tar extractor, then it is placed after the exhauster; this eliminates the deep seals necessary with high suction at the inlet to the exhauster. It is usually easier from an operating standpoint to handle gas under pressure than under suction. The exhauster

can be either of the positive displacement type or of the fan type, depending on the pressure required. Turbo exhausters have been tried on producer gas, but, up to date, have not been successful, since the tarry matter is so heavy and sticky that it does not free itself from the vanes. Wherever possible, exhausters should be steam driven, for steam lends itself much more readily to accurate control of pressures than electrically driven units.

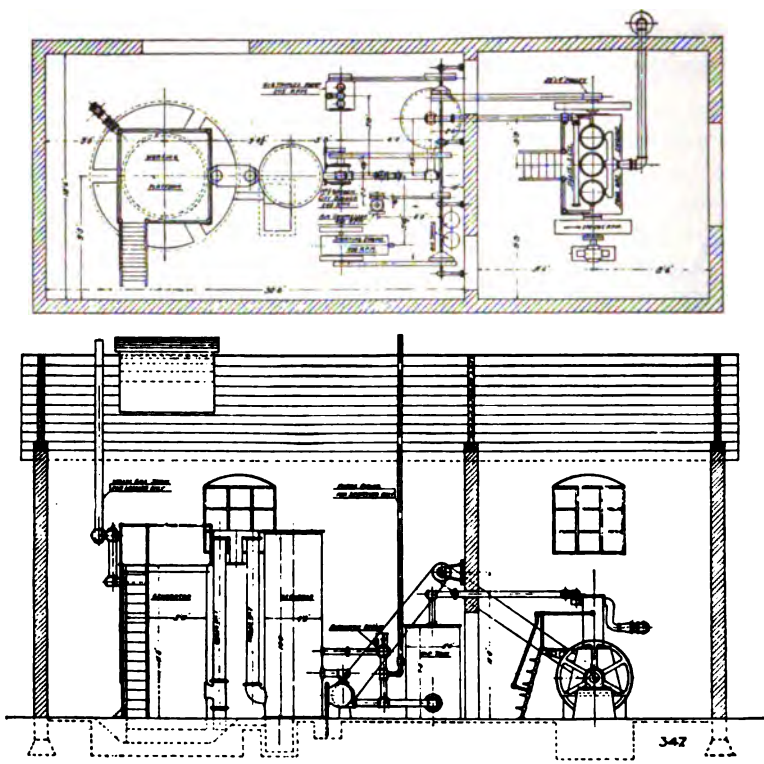


FIG. 299.—General arrangement of 100 hp. type B gas producer plant for the China Import & Export Lumber Company, Shanghai, China.

The exhauster should be placed as near as possible over the decanter, the same as the other apparatus. The gas lines leading to and from the exhauster should seal directly into the decanter, with no pocket for the possible accumulation of tar and water. A certain amount of tar always comes down in the exhauster unless it has been removed completely by a tar extractor. If the gas is to be used for power purposes, the gas from

the exhauster should be passed into a final cooling tower, where its temperature is reduced to the lowest possible point. This will tend to eliminate not only the water of saturation down to the

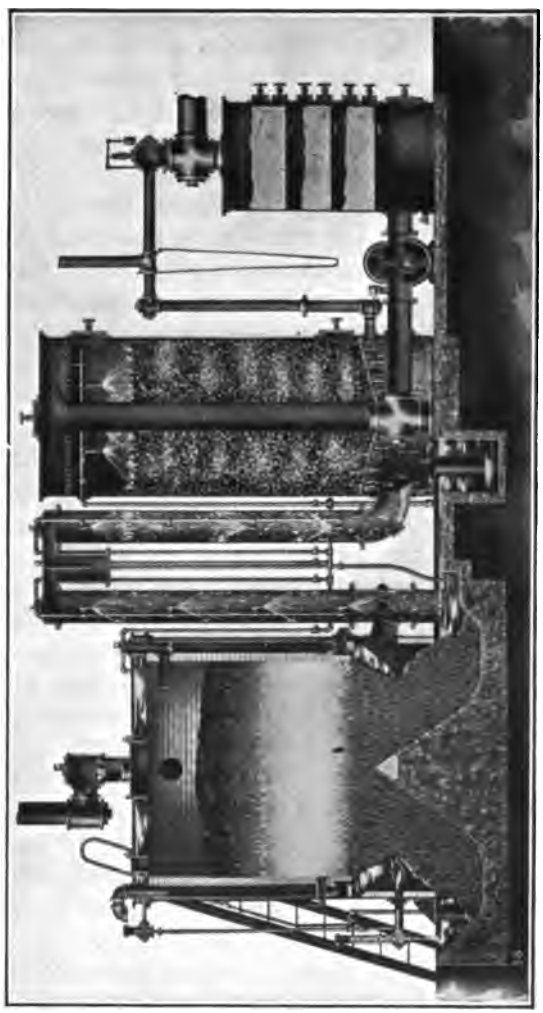


FIG. 300.—Sectional elevation of the Akerlund type "B" gas producer, built by Akerlund & Semmes, Inc., New York, N. Y.

point of cooling, but also the entrained water which is carried along with the gas.

At the point where the gas enters the distribution system, there should be a plant purge connected to the main piping by a valve,

and a valve in the main pipe immediately after the plant purge. This will make it possible to bleed the cleaned gas into the air before it is put into the distribution system. This purge is absolutely necessary from an operating standpoint. Each piece of apparatus throughout the plant also should be provided with a bypass, so that the apparatus can be cut out of the main line without shutting down the plant. Low-pressure gate-valves should be used for this purpose—a valve before and after each piece of apparatus, and one valve in the bypass. Only rising stem valves should be used on a gas plant.

The gas at this point is ready for distribution to the various points of consumption. The distribution lines must contain no undrained pockets; but if pockets are unavoidable, they should drain directly into a self-sealing seal. If this is not done, continual trouble will always be experienced by water forming in these pockets and sealing off the gas. This point cannot be overemphasized. After every precaution has been taken, the gas will still carry more or less entrained water.

The water for cooling the gas should enter the top of the tower, where the final cooling takes place, and drain directly into the decanter. The decanter should be provided with compartments wherein the water from the hot end of the plant can be kept separate from the water from the cool end of the plant. The hot water is pumped directly from the hot end of the decanter and recirculated through the dust catcher and collector main. Overflows are provided in the hot end of the decanter, so that the surplus liquor gradually works down into its cool end. Cooled water never should be used for spraying the hot gas. If the plant is so located that large quantities of fresh water are available, all the overflow can be drained from one point of the decanter. This water, however, after passing through the apparatus, becomes saturated with a very complex series of tars, phenols, sulphur, free ammonia, ammonium salts, etc.; and it should not be discharged into pure streams or where it can interfere with vegetable or animal life. At locations where a convenient method of disposing of this effluent liquor cannot be found, it can be cooled in cooling towers and recirculated. In this way, very little foul liquor is discharged from the plant. Cooling ponds may be used for cooling this liquor for recirculation; but, unless the sprays are designed carefully, a great deal of difficulty will be experienced in keeping them open. In spite of the best decantation,

a certain amount of tar and tar oils will be carried away with the liquor.

Tar is heavier than water and gradually accumulates in the bottom of the decanter. After a few hours of operation, the hot end of the decanter becomes coated with a thick scum of floating tars, which are held back by skimmers and baffles located through the decanter. This floating material, if kept at the hot end of the decanter, eventually sinks, since it is largely an emulsion of tar and water. If the accumulation of this tar becomes too serious, it is sometimes necessary to skim it off. The hot end of the decanter also should be provided with a lute, from which the heavy pitch can be removed if it is too heavy for pumping. This precaution is highly desirable since, with the best producer operation, there are times when the temperature of the exit gases becomes so high that quantities of free carbon or lamp-black are formed. This carbon mixes with the tar and forms a heavy pasty mass, which cannot be handled in pumps. The more fluid tars in the main body of the decanter can be pumped directly to the point of disposal. All pumps, including the tar pump, should be located below the level of the liquor, so that the pumps at all times will run with drowned suction; this is especially applicable to the tar pump. The shortest possible connection should be made between the decanter and the pump. Under the most favorable conditions, the pumping of tar is difficult. As stated in an earlier section of this Chapter, producer-gas tar has no market at the present time. It is entirely different from coal-gas tar, and the best method of disposing of it is to burn it under the boilers. Many attempts have been made to lead the tar to the producers and crack it to fixed gases, and some trials along this line have met with fair success; it is entirely possible to accomplish this result if the operation is carried out under the close supervision of an experienced man. If it is not broken up into a rather fine mist when discharging into the producer, it is liable to run through the fuel bed and come out with the ashes; this, of course, makes a hopeless mess of the ash removal. More work should be done along this line in the future, for it should be entirely possible to gasify completely all the tarry matter and at the same time appreciably enrich the gas.

The lower the temperature at which the producers can be operated, the more fluid the resulting tar will be. Producer-gas tar from low temperature operation, when distilled, contains

valuable oils from which germicides and insecticides have been made. At this writing, however, no market has been developed for these oils, and the result is that the tar is a liability rather than an asset.

The flow sheet in Fig. 301 shows the progress of the gas and liquor through the plant. It will be noted that each piece of apparatus drains directly into the decanter. Too much importance cannot be laid on this feature of the design.

TAR EXTRACTION

In the early applications of clean producer gas, modifications of the ordinary coal gas apparatus were used, such as the standard P. & A. tar extractor. The P. & A. depends for its effectiveness on first dividing the gas into fine streams and having these streams impinge on plates provided for that purpose. The result of this impingement of the tar-carrying gases is that the tar accumulates on the plate and runs down into the seal below. The loss of pressure over the machine represents the energy required to divide the gas into the small streams and causes it to strike the impingement plates with sufficient velocity to deposit the tar.

Washing and scrubbing the gas with water have been found to be wholly inadequate as a means of removing the tar. The bubbling type of apparatus, like the other simple means, removes some tar, but does not complete the operation. Sooner or later plants employing these means of tar extraction are obliged to install sawdust filters if complete removal of the tar is necessary, although the sawdust filter, or dry scrubber, as it is usually termed, requires too much cleaning and changing to make it an attractive apparatus.

In order to give the gas still severer treatment, centrifugal extractors and tar beaters of different types have been built. These have been made in a great number of different designs, but all operate on the same principle; that is, the gas is forced to enter the chamber containing the rotating part at the outside and is forced to leave at the center. The violent agitation combined with the centrifugal force is not only supposed to throw the tar fog to the outside of the machine, but also to bring about agglomeration of the tar particles by mechanical impact. When water is used in connection with these rotating members, a fairly complete removal of the tar can be attained. This method of tar

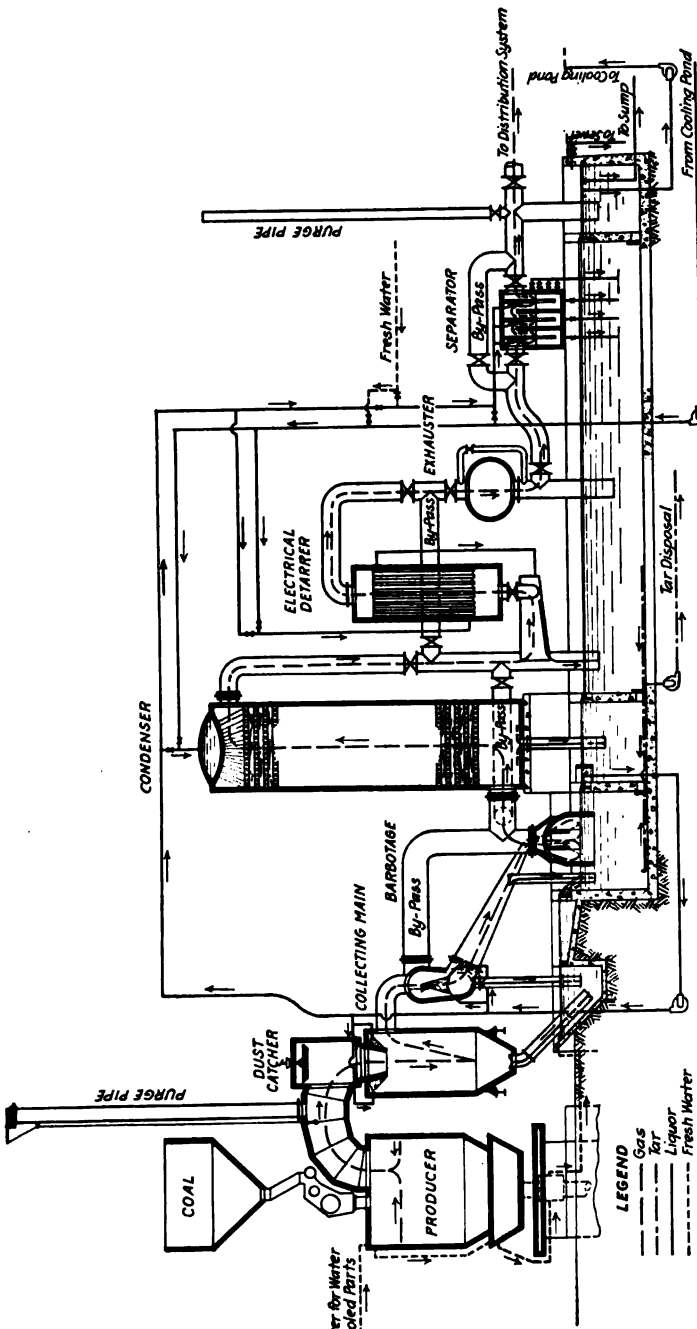


FIG. 301.—Flow sheet for producer gas condensing and cleaning plant. (*Steere Engineering Company, Detroit, Mich.*)

extraction in different forms has been installed commercially in a considerable number of plants. Inspection of these plants shows, however, that the larger percentage of them, for one cause or another, either have been changed or the entire plant dismantled.

The rotating tar extractor does not seem to have been a satisfactory solution of the problem. In the first place, high-speed machines of this type are not desirable around a gas plant. In the second place, the tar which is extracted in this way comes out as an emulsion of tar and water, making the tar still more difficult to dispose of. The cost of power for operating one of these machines is very high. The reason for this high cost goes back again to the difficulty of separating the tar fog from the gas. The almost molecular state of subdivision in which a certain percentage of the tar fog is found, makes it carry along with the gas with tremendous persistence. It therefore can be argued that the rotating type of tar extractor, which, to a certain extent, depends upon the centrifugal action working on the solid tar bodies, is the incorrect principle on which to attack the problem of detarring gas.

If the machines are eliminated which are built on the principle of the P. & A. tar extractor, which depend for their effectiveness on impact, and also the machines of the rotating type, there are only two other methods which suggest themselves as offering a possible solution. The first is to filter the tarry matter from the gas by bringing as far as possible each minute globule of tar in contact with the filtering surfaces. The second is by treating the gas in some manner which will bring about the coalescing of the tar globules, so that they will either settle out by their own weight or can be removed easily by mechanical means. In the first method, the problem can be worked out by building filters of very great size and filling them with sawdust. The gas then is passed through them at a very low velocity, and the tar fog is brought into intimate contact with the absorbing material. This method of attack, although giving fairly good results, is not only expensive to build but is expensive to keep up and requires a great deal of ground area. The author has studied installations of this type in operation, in which the filters were opened daily and the surface of the sawdust beds removed. This was done simply by starting at one side of the boxes and rolling up the top layer of sawdust, which had become impregnated with

the tarry matter, forming a sheet consisting of sawdust with tar as a binder. This was rolled up and thrown out of the box and the box again closed up. After a few days of this operation, more sawdust would be added to replace the material removed with the tar. This will also serve to illustrate the viscosity of the tar at ordinary temperatures.

A great deal of work has been done on the different processes for removing the tar by passing it through filters, which have been made of almost every material imaginable. There is on the market today a process for cleaning producer gas which consists of passing the gas through mats of glass wool. The gas is compressed to from 2 to 5 lbs. per square inch, depending on the cleaning required, and forced through these filters of spun glass. This scheme only works successfully on gas carrying a fluid tar—that is, containing a minimum of pitchy matter. It would follow naturally from a consideration of the material of which these filters are made that heavy tar would not pass through them. This difficulty, in practice, is in a measure overcome by using a producer of sufficient capacity to gasify the coal at a relatively slow rate and keep the temperature of the fuel bed as far as possible below the point where free carbon and pitch are formed. The resulting tar is of a much more fluid nature than is made in the producer working at higher capacity and lends itself very well to the treatment in the glass-wool filter. Many other schemes for filtering have been tried, but with indifferent success; for instance, wire cloth of fine mesh and tanks filled with steel borings, through which the gas is passed at high velocities.

When the tar fog is caused to agglomerate and form larger globules, the difficulty of removing the tar from the gas practically disappears. There are two ways in which this highly desirable condition can be brought about. First, the gas can be given sufficient time for the tar particles to agglomerate and settle out by gravity. Second, this agglomeration of the tar particles can be brought about by subjecting the gas containing the tar fog to high-tension electrical discharges. In the first method, the cost of installation obviously makes it prohibitive. Enormous holders would have to be erected, in which the gas could be brought to rest and remain in this state for hours, possibly days. The second method, however, offers very interesting possibilities. The high-tension electrical discharges may be either direct current or alternating current. The direct-current

process was brought out by Dr. F. G. Cottrell, the alternating-current process by the author. So far as can be seen, the fundamental principles involved in both these methods are very similar. A description of the theory of the alternating-current process will serve to illustrate this method of attack in cleaning producer gas.

The following account is an abstract of a paper entitled "Electrical Process of Detarring Gas," which was read by the author before the American Gas Institute in 1914.

In attempting to outline the electrical action, we must keep in mind, first, that the gas molecules themselves possess both positive and negative electrical constituents which can be separated by x-rays, beta and gamma rays of radium, brush discharges from points, corona discharges from wires raised to high potential, ultraviolet light, etc. This process of separating neutral gas molecules into electrically charged parts or ions is called "ionization." It is inappropriate here to attempt to discuss the ionic theory, but it should be noted that ions as such are very unstable and cease to exist, that is, recombine to form neutral molecules, almost the instant they are outside the ionizing influence. A very few molecules are continually splitting up, presumably because of the trace of radio-active substances found in most gases as well as in the atmosphere.

Prof. R. A. Millikan, of the University of Chicago, has studied the movements of a small drop of oil between two oppositely charged condenser plates when attacked by atmospheric ions. The drop receives a charge when atomized, so, by throwing on and off the electrical field, the drop is made to beat up and down between the plates. The instant an ion attaches itself to the drop, the fact is made known to the observer by its change in speed, this change depending on the sign of the ion and the charge on the drop. The important and interesting thing to note is that, with over a thousand drops studied in this way, the change of speed was always exactly proportional to the number of ions attached to the drop.

Let us recall that there are about 27,000,000,000 molecules in 1 c.c. of ordinary air and that each molecule may be separated into at least two ions. When just one of the possible 54,000,000,000 ions per cubic centimeter attached itself to the oil drop, it instantly caused an appreciable change in its velocity. Imagine, then, the violence with which this drop would have been thrown about if all the molecules surrounding it had been ionized.

This is just the condition we bring about in the electrical detarrer. The gas carrying the minute tar globules is swept into an intense ionizing field. Billions of gas molecules on every side are being torn apart.

The resulting ions rush madly about in their effort to recombine. The unsuspecting tar globules find themselves in a storm center of unseen forces hurling them in every direction. The time occupied in the passage of the tar particles through the electric field is brief and it might naturally be supposed, as it heretofore has been, that an aimless to and fro movement of them would be the result of the applied energy. It would, however, be hard to conceive of a condition more favorable to impact between tar particles; and experience shows that either because of this impact, or for some reason as yet unknown, agglomeration results and the dense tar mist is almost entirely dissipated, leaving a relatively few large tar drops in its place. This rather figurative description will seem more real to those who have witnessed this remarkable phenomenon within a glass vessel filled with dense fumes or fog. The instant current is turned on, the whole field can be seen to clarify. The commercial importance of this becomes more apparent when we realize that this action can be brought about at almost any desired temperature.

The electrical processes show real possibilities. There is absolutely no question that tar vapor can be removed completely from gas by these methods. They also have the advantage of being more nearly independent of temperature than any of the mechanical processes. The power consumed with the electrical process is very low, requiring approximately 3 hp. per million cubic feet of gas treated. The application of electrical processes is distinctly new and, as in all new processes, requires more or less experimental work in connection with each different installation. These matters, however, are getting very well worked out and it is now safe to say that the electrical detarring processes are commercially successful and can be relied on for regular and continuous operation.

There has been considerable question in the minds of some gas engineers as to the advisability of having an electrical spark discharging through the gas, the argument being that if, from any accidental cause, air has been admitted to the gas line, an explosion is sure to follow. There is no question but that this is so. The answer to this argument is that there should not be an explosive mixture of gas and air in the pipe line. As soon as such a condition occurs, whether an electrical process is used for detarring the gas or not, a very serious danger is presented. This mixture of gas and air may carry on to the distribution line, furnaces, or wherever the gas is to be used, and is liable to explode in any one or all these places. It therefore can be argued

that an electrical process which will explode such an explosive mixture in the plant is a safety factor rather than a source of danger, inasmuch as the apparatus can be designed so that an explosion will do absolutely no harm to the plant and cause practically no interruption to the gas-making process. It must be recalled that producer gas is a very weak gas and that an explosive mixture of producer gas and air under slight pressure does not give as violent an explosion as the richer gases.

COST OF GAS

In order to get accurate comparisons among the costs of the different fuels, all these costs should be reduced to a B.t.u. basis. Money is spent for B.t.u.'s, not for volume of gas. In order to illustrate the cost of producer gas, the following somewhat detailed figures are given on the items which go to make up the total cost of the gas. The cost of gas depends upon the conditions surrounding each installation, and the cost under any condition can be figured by substituting the revised figures for the figures given. These costs are: fuel, power, repairs and incidentals, interest and depreciation on the investment, and labor for operation.

The figures which are given on the cost of the plant, buildings, equipment, etc., are based on actual cost figures with pig iron selling at $35 per ton. These figures take into account all the expense required to make a plant ready for operation. It may be added here that another unfortunate mistake which has been made by both engineers and gas equipment manufacturers in the past, is the underestimating of the total cost of an installation. Figures are submitted which may be complete and accurate as far as they go. The client assumes that these data cover all the cost to which he will be put in making his plant a going concern. The many little items which are necessary to make a gas plant operative, outside of the main construction, amount to an appreciable percentage of the total cost.

Consider first the cost of clean cold gas made from bituminous coal in a plant having a capacity of 15,000,000 cu. ft. of gas per 24 hrs., to be located under the most favorable conditions for low-priced fuel. Assume the cost of the coal at the plant siding to be $2.50 per ton.

Coal:

15,000,000 cu. ft. of producer gas represents 125 tons coal.

Cost of coal at plant—$2.50 per ton.

Cost of coal per 24-hr. day..... $312.50

Power:

125 tons of coal per day—250,000 lbs.

⅜ lb. of steam per pound of coal gasified—93,750 lbs. of steam used in producer plant.

Steam at 30 cts. per 1,000 lb.....	$28.12		
Operating mechanical producers...	25 hp.		
Pumping and cleaning gas.....	150 hp.		
Pumping cooling water, liquor and tar.....	50 hp.		
Lighting.....	15 hp.		
Coal and ash handling.....	25 hp.	265 hp.	
Figuring 1 ct. per hp.-hr.—			
Power.....			$63.60
Steam.....			28.12
Total power charge per 24-hr. day.....			$91.72

No cost is put in for water, other than the pumping charge.

Repairs and Incidentals:

This item includes oil, waste, packing, etc., and can only be estimated. It does not include labor.

Experience indicates that $25 per day, or $9,125.00 per year, is conservative.

Cost of plant:

5 mechanical producers @ $15,000 each...	$75,000.00	
Condensing-plant apparatus, from producers to outlet of separator, complete, except tar, liquor and steam piping.....	120,000.00	
Tar liquor and steam piping, effluent liquor and tar disposal.....	12,000.00	
Foundations.....	20,000.00	
Erection of producer plant equipment.....	15,000.00	
Buildings, coal and ash handling.....	50,000.00	$292,000.00

Power plant for steam and electricity is not included. The overhead charge on this plant is, however, taken care of in estimating steam at 30 cts. per 1,000 lbs. and in estimating power at 1 ct. per hp. hour.

No allowance is made for real estate.

Interest and Depreciation.

Interest and depreciation at 15 per cent.

Interest and depreciation charged per 24-hr. day..... $120.00

Labor per 24-hr. Day:			
Superintendent		$10.00	
Producer men—5 per 8-hr. shift	15 man days		
Condensing plant—1 per shift	3 man days		
Coal and ash handling—2 men for 2 shifts	4 man days		
Repair man and helper—each shift	6 man days		
Labor at $4.50 per 8-hr. day	28 man days	$126.00	$136.00
Recapitulation			
Coal		$312.50	
Power		91.72	
Repairs and incidentals		25.00	
Interest and depreciation at 15 per cent		120.00	
Labor		136.00	
Total cost for producing 15,000,000 cu. ft. clean producer gas			$685.22
Total cost for gas per 1,000 cu. ft.			4.568 cts.

Assuming that the producer gas will run 145 B.t.u. per cubic foot, the total cost of this gas then figures 31.5 cts. per million B.t.u. Producer gas, then, under these very favorable conditions of fuel cost on a B.t.u. basis, is equivalent to natural gas at 34.65 cts. per 1,000 cu. ft. There are few places reached by natural gas today where the price of natural gas for industrial purposes exceeds 35 cts. per 1,000 cu. ft. It should be noted, especially in connection with this price of 4.568 cts. per 1,000 cu. ft. for producer gas, that a 100 per cent load factor has been assumed. That is, the plant is figured as running every day in the year for 24 hrs. per day at full-rated capacity. If it is assumed that this plant has 50 per cent of load capacity for the year, the cost of gas immediately jumps to around 6.5 cts. per 1,000 cu. ft., which is equivalent, on a B.t.u. basis, to natural gas at 50 cts. per 1,000 cu. ft.

In the figures on the cost of plant, no spare producer capacity or engine and exhauster capacity has been provided for. One extra producer and an additional engine and exhauster would be necessary if the plant were run with a load factor around 100 per cent.

From the analysis given above, it is a simple matter to substitute figures for any location or set of conditions and arrive at a very close approximation of the cost of gas under almost any condition. The plant investment increases somewhat

per unit of capacity in plants of smaller capacity. Very large plants do not decrease in the cost per unit of capacity beyond the cost of a plant of 15,000,000 to 20,000,000 cu. ft. per day, the reason for this being that where large quantities of gas are handled the apparatus is built in duplicate, as it is not economical to enlarge beyond a certain point.

In estimating the cost of gas from coke or hard coal, the investment in the plant may be considered as 15 per cent less than with the soft coal plant, as given above.

COST OF HOT RAW PRODUCER GAS

The cost of hot raw gas must be figured at the producer offtake, and the expense of distribution calculated as a separate item. Consider the same plant that has been analyzed for clean cold gas, that is, 125 tons of coal per 24 hrs., with a 100 per cent load factor. The cost of hot gas at the producer offtake will be 3.54 cts. per 1,000 cu. ft., which is equivalent to natural gas at 26.9 cts. per 1,000 cu. ft. If the plant is run with a 50 per cent load factor, the cost of gas will be 5.04 cts. per 1,000 cu. ft., which corresponds to natural gas at 38.2 cts. per 1,000 cu. ft. on a B.t.u. basis. It must be clearly noted that these figures are given as the cost of gas at the producer offtake.

In order to arrive at the true cost of artificial gas as compared with natural gas, consideration must be given to the investment in the flues up to the point of consumption. As has been pointed out before, this is a very serious item of cost when the gas has to be carried appreciable distances. Moreover, the labor for keeping these flues clean and the loss of capacity due to the enforced shutdowns for burning out should be figured in the cost of hot raw gas. These are items which can only be determined for each particular case, for the layout and extent of the distribution system vary at every plant.

An analysis of these cost data shows clearly that, as the present supply of natural gas fails, higher fuel costs are inevitable. Producer gas under present conditions cannot even begin to compete with natural gas, unless the coal is figured at practically nothing.

The table shown on page 968 has been compiled to show the costs at which natural gas, fuel oil, coal gas, and blue gas, or uncarbureted water gas, must be bought to obtain the same number of B.t.u. as when buying producer gas with coal at various prices. It must be kept in mind that this comparison

is on a B.t.u. basis only and that no account is taken of the relative efficiencies of the industrial applications of the fuels.

Producer Gas Costs

The following table of producer gas costs includes fuel, power, repairs and maintenance, labor and supervision, interest and depreciation; in fact, every item of cost except the interest and taxes on the land occupied. This information has been compiled and checked in detail by the Steere Engineering Co. and its engineers exclusively, although it has been copied and appears in a bulletin issued by another organization.

Producer gas costs per 1,000 cu. ft. for coal costs given			Costs at which other fuels must be bought to obtain the same number of B.t.u. as when buying producer gas with coal at the price given							
Cost of 1 ton of coal at plant	Hot raw producer gas at offtake	Clean cold producer gas	Natural gas per 1,000 cu. ft.		Fuel oil per gallon		Coal gas or carbureted water gas per 1,000 cu. ft.		Blue gas per 1,000 cu. ft.	
	cents	cents	Hot raw gas, cents	Clean cold gas, cents	Hot raw gas, cents	Clean cold gas, cents	Hot raw gas, cents	Clean cold gas, cents	Hot raw gas, cents	Clean cold gas, cents
$2.00	3.13	4.15	23.7	31.5	2.91	3.86	12.6	16.72	6.45	8.59
2.50	3.55	4.57	26.9	34.67	3.3	4.25	14.3	18.40	7.34	9.45
3.00	3.96	4.98	30.1	37.84	3.69	4.64	16.6	20.09	8.20	10.32
3.50	4.38	5.40	33.3	41.01	4.08	5.03	17.65	21.77	9.07	11.18
4.00	4.79	5.82	36.3	44.18	4.46	5.42	19.3	23.45	9.92	12.05
4.50	5.21	6.24	39.5	47.35	4.85	5.81	21.0	25.13	10.78	12.91
5.00	5.63	6.66	42.7	50.52	5.24	6.20	22.7	26.82	11.65	13.78
5.50	6.05	7.08	45.9	53.69	5.63	6.59	24.35	28.50	12.5	14.64
6.00	6.46	7.49	49.1	56.85	6.01	6.97	26.0	30.18	13.36	15.50

Heating Values Used

Producer gas	145 B.t.u. per cubic foot
Natural gas	1,100 B.t.u. per cubic foot
Fuel oil	135,000 B.t.u. per gallon
Coal gas or carbureted water gas	585 B.t.u. per cubic foot
Blue gas	300 B.t.u. per cubic foot

Note: These costs are based on the plant operating with a 100 per cent. load factor, that is, operating at rated capacity 24 hr. per day, 365 days per year. Comparatively few plants have a 100 per cent load factor; therefore, it is necessary to take this very important point into consideration when estimating the cost of gas.

The cost of producer gas, with a reasonable degree of accuracy, may be estimated for any load factor by applying the formula:

$$C = T + \left[\left(\frac{R \times 400}{A \times B}\right) - 2.38\right]$$

Where C = Cost of producer gas per 1,000 cu. ft. under conditions specified
A = Number of feet of gas used per day
B = Days per week plant is in operation
T = Cost figures shown in table at 100 per cent load factor
R = Rated hourly capacity of plant in cubic feet

BY-PRODUCT PRODUCERS

The question of by-product recovery from producer gas is receiving a great deal of attention at the present time. In the minds of many people, there is some confusion in connection with by-product recovery from producer gas and by-products from coke oven gas. The only commercially valuable by-product which ever has been recovered from producer gas on a commercial scale up to this time is ammonia, usually in the form of sulphate. While ammonia, tar, cyanides, light oils consisting largely of benzol, toluol and xylol, etc., are recovered from coke oven gas.

If ammonia is to be recovered on a commercial scale, the process of manufacturing producer gas must be altered somewhat in order to increase the yield of ammonia to the highest point possible. Producer gas, as ordinarily made in either the hand-poked or mechanically operated producer, does not carry more than the equivalent of from 15 to 20 lbs. of ammonium sulphate per ton of coal gasified. A much thicker fuel bed must be carried in the producer if the maximum amount of ammonia is to be recovered per ton of coal. The temperatures in a by-product producer are kept as low as possible throughout the fuel bed. The low temperatures are necessary to prevent the decomposition of the ammonia as the gas is evolved. In straight producer operation, approximately $\frac{3}{8}$ lb. of steam is used for each pound of coal gasified. In by-product producer operation, around $2\frac{1}{2}$ lbs. of steam are used for each pound of coal gasified. In order to maintain the temperature conditions in the producer and still pass this quantity of steam through the fuel bed, it must be superheated to at least 500°F. before it is blown into the producer. The usual method is to introduce this steam or water vapor into the blast and then superheat both the air and steam with the sensible heat of the gases leaving the producer. With all this water vapor raised to the temperature of the exit gases at the expense of the heat in the fuel bed, it is obvious that some method must be used to recover at least a part of it, or the thermal efficiency of the producer would be so low that it would offset the value of the ammonia recovered. The difficulty of satisfactorily recovering this heat has in no small measure militated against the success of the by-product producer process.

In this country, by-product producer recovery plants are thought of usually in the terms of the Mond process, which has

been worked out successfully in England. Up to this time, two installations of the Mond process have been made in this country. The first installation was made at the Detroit plant of the Solvay Process Co., and the second installation was at the Wyandotte plant of the Michigan Alkali Co. The Solvay plant, after having been shut down for some time, was dismantled somewhere about 1910. The Wyandotte plant was discontinued about 1915, but the apparatus is still standing. The interesting question in connection with these installations has been: "Why were they abandoned?" All the reasons which have been given may be concentrated to simply this—they did not pay. The work which they were installed to do could be done cheaper in other ways.

Very recently two by-product producer plants have been completed in this country and now are being tried out. In fundamental principle they are no different from the Mond plants, but certain modifications have been made in the design of the apparatus. They have not been in run long enough at this time so that information is available as to whether or not they constitute a commercial success. These are the only commercial attempts which have been made at by-product producer operation in the United States up to this time.

The flow sheet shown in Fig. 302 will give a clearer idea of the process of manufacturing producer gas and the recovery of ammonia from this gas. It should be noted that this flow sheet must not be considered in any way as a design, but is made simply to show the sequence of apparatus and the flow of gases, liquor, and acid. The principles here illustrated are fundamental and are the basis of all attempts at the recovery of ammonia from producer gas.

Coal is charged into the producer, or gas generator, as shown, and the gas passes out through the offtake and dust catcher. The gas leaving the dust catcher normally has a temperature of 1,000°F. and is supersaturated with tar vapors and some free carbon. It next passes through the blast superheaters, wherein the temperature of the gas is reduced to approximately 600°F. Immediately following the blast superheaters, the gas is saturated with water vapor by being washed in some form of spraying or bubbling apparatus, which takes out the heaviest part of the dust and dirt. This washing must be done with hot liquor and continuously recirculated in a closed system to prevent the

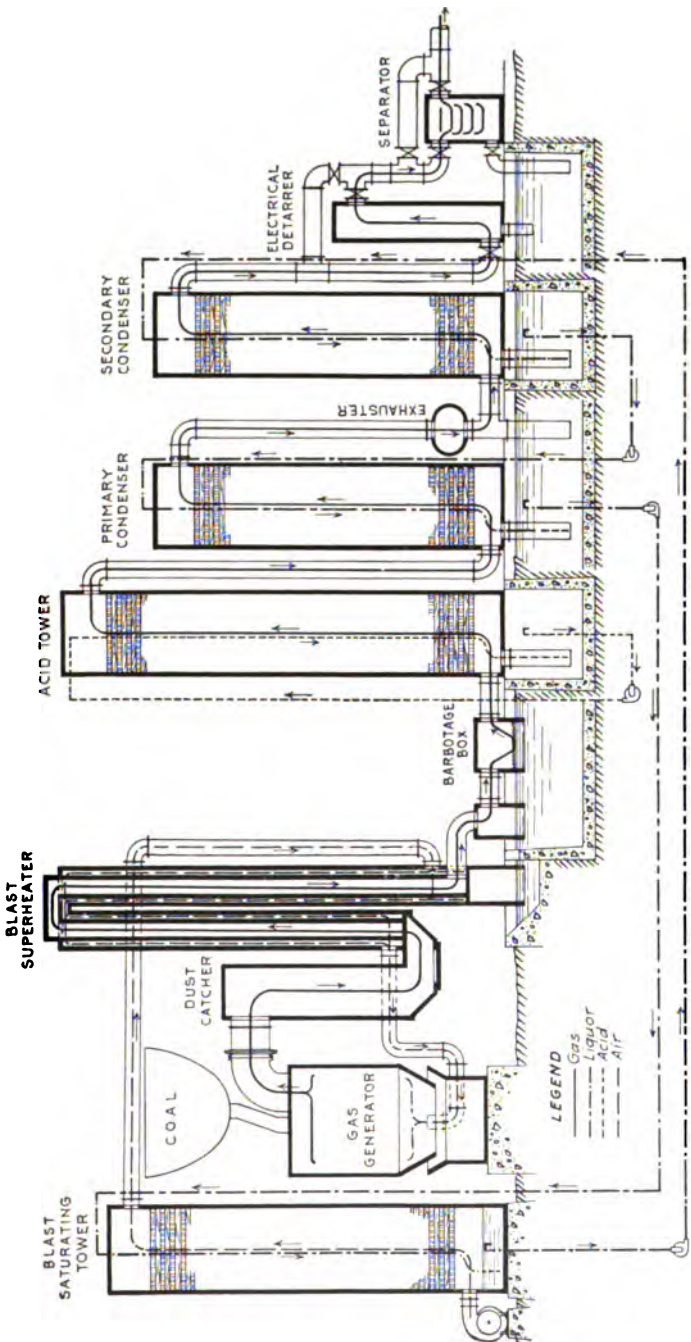


FIG. 302.—By-product producer gas plant, Steere Engineering Company, Detroit, Mich.

making sulphate; but as the cost of acid and price of sulphate vary approximately together, it is unnecessary to assume more than one figure, namely, the present market price of each.

Sulphate Obtainable from 1 Ton of Coal.—All the ammonia is derived from the nitrogen present in the coal. An examination of U. S. Bureau of Mines *Bull.* **85** shows that 1.4 per cent of nitrogen is a fair average value for American coals. If all this 1.4 per cent of nitrogen were recoverable as ammonium sulphate, the amount would be 132 lb. of $(NH_4)_2SO_4$ per ton of coal. That not all this is recoverable as sulphate will be apparent from the following considerations:

1. Coal gas (11,000 cu. ft. per ton) commonly contains 2 per cent of free nitrogen not recoverable as ammonia. This 2 per cent represents 17 lbs. of nitrogen per ton of coal, or 80 lbs. of sulphate. Of course, part of the nitrogen may have leaked into the gas during manufacture, but it is the general opinion that the greater part of it comes from the coal.

2. After the volatile matter is driven off by carbonization, the resulting coke commonly contains 1 per cent of nitrogen. If this nitrogen were recoverable as ammonia, some of it would be recovered in the water gas process, and it is notable that very little ammonia is found in water gas.

3. Producer gas, as ordinarily made, with no special attention to the recovery of ammonia, runs from 15 to 25 lbs. of sulphate per ton of coal gasified. All things considered, it would appear that 60 to 90 lbs. of sulphate per ton of coal cover the range of possibilities. Sixty to 70 lbs. have actually been made on a commercial scale, and no doubt 80 lbs. can be made by sacrificing the quality of the gas. Much larger amounts are claimed by some promoters of this process, but in this country from 45 to 60 lbs. have been much nearer the actual results from the plants which have been operated. These figures should be used until it has been proved by operating experience that more can be made and at the same time make gas that can be used commercially.

TYPE OF PLANT NECESSARY

To obtain the maximum yield of ammonia, the following variations from normal producer gas practice have been found to be desirable:

1. Top temperature of fuel bed at 900 to 1,100°F.
2. Depth of fuel bed increase to 6 ft.
3. Steam in blast increased to 2½ tons of steam per ton of coal.
4. Pre-heating of blast.

ELEMENTS OF COST

The cost of producer gas is made up from the following items:

1. Cost of coal.
2. Cost of steam for saturating blast.
3. Cost of steam for pumping gas.
4. Cost of power.
5. Cost of labor.
6. Repairs and incidentals.
7. Interest and depreciation.

The cost of recovering ammonia as sulphate is made up from the following:

8. Extra steam.
9. Steam to evaporate sulphate liquor.
10. Extra power.
11. Extra labor.
12. Sulphuric acid.
13. Repairs and incidentals on equipment for ammonia recovery.
14. Interest and depreciation on equipment for ammonia recovery.

The costs of producer gas without ammonia recovery are analyzed on pages 967 to 969. A summary of these costs for different prices of coal is given in the table on page 968.

In order to bring out clearly the items of cost entering into ammonia recovery, the following analysis is presented.

In figuring these costs, only those charges have been allowed which are made necessary by equipping the plant for ammonia recovery. All other charges have been absorbed in the cost of producer gas: items 1, 2, 3, 4, 5, 6, and 7.

Item 8. Extra Steam.—Experience has shown that, to produce the highest possible yield of ammonia, it is necessary to blast the producer with around 2½ tons of steam per ton of coal gasified. Part of this steam will be supplied by the exhaust from the various engines in the plant. Another part will come from the air saturating tower in which the hot liquor is pumped through the air-blast. The balance will have to be supplied as live steam.

Steam used in regular practice—⅜ lb. per pound of coal, Item 2	90,000 lbs. daily.
Steam to pump gas, Item 3	108,000 lbs. daily.
Water vapor available from air saturating tower (see note below)	195,000 lbs. daily
Total	393,000 lbs. daily
Daily requirements at 2½ tons per ton of coal	600,000 lbs. daily
Difference to be supplied as live steam	207,000 lbs. daily

At the evaporation rate of 7.65 lbs. of steam per pound of coal used before this would require $\frac{207,000}{7.65}$ = 27,000 lbs. = 13½ tons daily.

Cost of extra steam for blast with coal at $3, $4, $5 and $6 per ton and overhead charge of 10 per cent on boiler plant = $44.60, $59.40, $74.20 and $89.10.

Item 9. Steam to Evaporate Sulphate Liquor.—The solution can be made up to 18° Twaddle in the acid tower, or 8¼ per cent by weight of sulphate. This strength gives good decantation between the tar and the acid solution. For every ton of sulphate made, it will be necessary to evaporate 11.1 tons of water, requiring for this purpose an equal weight of steam. With 80 lbs. of sulphate per ton of coal, and with coal at $3, the daily charge would be $20.88. Probably none of this item of $20.88 would be an added expense because the extra 207,000 lbs. (item 8) of live steam required by the blast could be taken through the evaporator, thus carrying the evaporated liquid into the blast. The steam after leaving the coils of the evaporator would be very wet, but it could be put into the blast just before entering the superheater, which would evaporate the entrained moisture again.

In consideration of the above, no charge has been allowed for evaporating the sulphate liquor, although in practice very likely all, or a part of, this expense would have to be added.

Item 10. Extra Power.—Any extra power required to pump the gas through the additional apparatus will reduce the excess amount of live steam required, so no addition need be made. One additional pump (10 hp.) will be required to pump liquor through the acid tower.

10 hp. at 1 ct. per hp.-hr. for 24 hrs.....$2.40.

Item 11. Extra Labor.—For attending to the evaporator and acid tower:

2 men on day shift	2 man days	
1 man on each night shift	2 man days	
Total	4 man days	
Cost per 8-hr. day at $4.50		$18.00

Item 12. Sulphuric Acid.—The chemical reaction involved is:

$$2\ NH_3 + H_2SO_4 = (NH_4)_2SO_4.$$

Theoretically, 98 lbs. of 100 per cent sulphuric acid make 132 lbs. of sulphate, so for each 100 lbs. of sulphate 74 lbs. of acid are required. In practice, an allowance has to be made for weak acid, leakage, etc., allowing 20 per cent for this, or 89 lbs. of acid per 100 lbs. of sulphate.

Wholesale prices, f.o.b. works, on 66°Bé. sulphuric acid (95 per cent H_2SO_4) are assumed to average $25 per ton.

66° sulphuric acid can be shipped in tank cars, fifth class.

Assuming that it can be bought within 250 miles of the gas plant, the freight charge would be 20 cts. per 100 lbs. or $4 per ton.

The cost of acid delivered to the plant would be $25 plus $4 equals $29 per ton, or 1.45 cts. per pound.

On a plant gasifying 120 tons of coal per day, the daily charge for acid would be as follows:

@60 lbs. of sulphate per ton of coal	$92.90
@70 lbs. of sulphate per ton of coal	108.50
@80 lbs. of sulphate per ton of coal	120.38
@90 lbs. of sulphate per ton of coal	139.40

Item 13. Repairs and Incidentals.—Repairs chargeable to ammonia recovery would be on the following apparatus:

superheater,
saturator,
acid tower, and
evaporator.

Since the sum of $25.00 per day has already been charged to the general plant, an additional charge of $5.00 per day should be sufficient after the plant has been put in good operating condition.

Item 14. Interest and Depreciation on Special Equipment for Ammonia Recovery.—

Extra cost for special producers @$5,000.00 each	$30,000.00	
6 superheaters	30,000.00	
1 blast saturating tower	4,000.00	
1 acid tower	10,000.00	
1 acid tank	2,500.00	
2 acid pumps	2,000.00	
1 air blower	7,000.00	
1 evaporator	2,500.00	
	$88,000.00	
Interest and depreciation on $88,000 at 13⅓ per cent, cost per day		$32.12

RECAPITULATION OF COST WHERE AMMONIA IS RECOVERED

	Coal at				
	$2	$3	$4	$5	$6
Item 8—Extra steam	$29.70	$ 44.60	$ 59.40	$74.20	$ 89.10
Item 9—Evaporation (no charge)					
Item 10—Extra power	2.40	2.40	2.40	2.40	2.40
Item 11—Extra labor	18.00	18.00	18.00	18.00	18.00
Item 13—Repairs and incidentals	5.00	5.00	5.00	5.00	5.00
Item 14—Interest and depreciation	32.12	32.12	32.12	32.12	32.12
Total of all charges except acid—	$87.22	$102.12	$116.92	$131.72	$146.62

Sulphate recovered per ton coal—	60 lb.	70 lb.	80 lb.	90 lb.
Item 12. Cost of sulphuric acid.—	$92.90	$108.50	$120.38	$139.40

COSTS OF SULPHATE

The market prices of ammonium sulphate per pound f.o.b. New York City have been as follows:

1910	$0.0278
1911	0.0311
1912	0.0328
1913	0.0314
1914	0.0271
1915	0.0330
1916	0.0388
1917	0.0600
1918	0.0780
1919	0.0425
1920	0.0480
1921	0.0300

In the following discussion, a price of $75.00 per ton has been assumed for a good grade of ammonium sulphate, f.o.b. works.

The results of recovering ammonia can be shown best in tabular form. The two tables given below show the costs of the gas, cost of producing the sulphate, and possible profits, etc., based on the above analysis of costs of operation. It must be kept in

mind that these figures are purely theoretical and that to date no plant in this country has been proved a commercial success. There is no doubt but that the possible profits are worth going after and it is to be hoped that the work along these lines now in progress will result in some definite information as to just what can be expected.

TABLE CVII

Coal per ton delivered	Pounds of sulphate per ton of coal			
	60	70	80	90
$6.00	$66.50	$ 60.70	$ 55.60	$ 53.00
	34.20	60.00	93.10	118.90
5.50	64.45	58.95	54.05	51.65
	38.00	67.40	100.50	112.10
5.00	62.40	57.20	52.50	50.30
	45.40	74.80	108.00	133.40
4.50	60.35	55.45	50.95	48.90
	52.80	82.10	115.50	125.20
4.00	58.30	53.70	49.40	47.50
	60.10	89.50	122.80	148.50
3.50	56.25	51.85	47.87	46.10
	67.50	97.20	130.20	138.60
3.00	54.20	50.00	46.35	44.70
	74.90	105.00	134.60	163.60
2.50	52.15	48.42	44.80	43.35
	82.30	111.50	145.00	152.00
2.00	50.10	46.85	43.25	42.00
	89.60	118.20	152.40	178.20

Cost (upper figure) per ton of sulphate with sulphuric acid at $29 per ton delivered.

Profit (lower figure) per day on plant gasifying 120 tons daily with sulphate at $75 per ton.

TABLE CVIII

Coal per ton delivered	Pounds of sulphate per ton of coal			
	60	70	80	90
$6.00	$0.075 0.517	$0.073 0.504	$0.0707 0.488	$0.069 0.476
5.50				
5.00	0.0648 0.447	0.0627 0.433	0.0604 0.416	0.0587 0.405
4.50				
4.00	0.0544 0.375	0.0523 0.361	0.05 0.345	0.0483 0.333
3.50				
3.00	0.0441 0.304	0.042 0.29	0.0392 0.27	0.0379 0.261
2.50				
2.00	0.0337 0.2325	0.0317 0.2185	0.0293 0.202	0.0275 0.19

Cost (upper figure) of 145 B.t.u. gas per 1,000 cu. ft.

Equivalent cost (lower figure) of 1,000 B.t.u. natural gas per 1,000 cu. ft. when profits from ammonia recovery are used to reduce cost of gas.

APPLICATION OF PRODUCER GAS

Owing to the large volume occupied by producer gas per B.t.u., the expense of transporting it is very high as compared with natural gas, which carries approximately seven times the heat energy per unit of volume. On the other hand, producer gas can be made wherever fuel can be obtained. Natural gas, of course, must be piped from the very restricted areas in which it is found.

There is no question but that it is highly desirable from a commercial standpoint to be able to obtain fuel ready for use rather than to assume the responsibility of producing it. The smaller the installation, the less desirable the isolated plants become.

One of the most attractive methods of solving the problem of artificial gas is the community gas plant. By this means, groups of industries within a radius of a few miles of one another can all be served from the same plant. The plant then can be of such a size that the investment charge and the operating expense can be reduced to a minimum. Every subscriber to such power will have the benefits of an individually owned plant without having to assume the responsibility of its operation. This idea can be worked out in many different ways and offers a very attractive field for investigation.

When considering the use of producer gas in new fields, it is very often found that there can be no saving over direct firing with coal. This is true in a surprising number of possible applications. However, if the smoke nuisance is taken into consideration, this gives producer gas firing a distinct advantage. Much work has been done on the firing of boilers with producer gas, but, outside of the elimination of smoke, it seems to offer no advantages over the very efficient types of modern stokers which are now available.

Producer gas has been used quite extensively in gas engines for power plant work. Although this looks very good on paper and in many cases will show a decided economy, the many operating features which still have to be overcome, both in connection with the producer plant and in connection with the design of the gas engine, especially of the larger type, lead inevitably to the conclusion that producer gas power is yet a long way from being able to compete successfully with the modern steam plants. The cost of the plant and the ground area required for a producer gas power plant are also greater than with a steam plant. Much more progress has been made abroad in the application of producer gas power plants, especially of the smaller sizes, than has been made in this country. This is attributable, unquestionably, to the foreign fuels, which seem to adapt themselves much better to gas producer practice than American fuels.

Producer gas is used today very extensively in connection with the iron and steel industries for the firing of open-hearth furnaces, soaking pits, etc. Producers also are used extensively in the zinc and glass industries. Many producer gas plants can be found successfully operating today in the very heart of the natural gas country, firing glass tanks. This, of course, is only

possible where coal can be obtained at a very low cost. In some cases, it is taken from the mines and dumped directly into the gas producers.

The following are a few of the industries which offer possible fields for the gas producer, and in some of which producer gas already has been worked out successfully: Japanning, annealing, tempering, type-casting, drying and heating of molds, bake ovens, cooking, brick burning, lime and cement burning, and ore roasting.

PRODUCER GAS IN THE AUTOMOBILE INDUSTRY

As an illustration of some of the work which has been done in connection with the heat treating of automobile parts, the following extract from a paper read by the author before the Society of Detroit Chemists, Local Section of the American Chemical Society, on May 17, 1917, may be of interest:

Let us confine our attention to the application of clean, cold producer gas to some of the heating operations which are generally done with other fuels, such as oil, for example. We will first run over, briefly, the types of furnaces which may be adapted to the use of producer gas. These can best be discussed under the following headings:

Double regenerator,
Single regenerator,
Double recuperator,
Single recuperator,
Combination regenerator and recuperator, and
Simple furnace where no waste heat is recovered.

For the purposes of this discussion, we will define regeneration as a reversing process, in which the gas or air, or both, is first brought in contact with heated surfaces, usually checkerwork, which, in the previous cycle, has been heated by being in contact with the heated products of combustion leaving the furnace. This is the old Siemens process with which you are all familiar.

We will speak of recuperation as the non-reversing process where the products of combustion give up their heat to the incoming gas and air by conduction and radiation through the flue walls. The incoming and outgoing gases are always kept in separate flues.

It is possible to obtain a higher furnace efficiency with producer-gas firing and double regeneration than it is possible to obtain with oil. The reason for this possible high efficiency is that the sensible heat of

the products of combustion is just about equal to the quantity of heat required to raise the gas and air for combustion to the same temperature as the products of combustion leaving the hearth.

To illustrate, assume a double regenerative furnace working with a hearth temperature of 1,650°F. There will be enough heat in the products of combustion to raise the temperature of the incoming gas and air to 1,650°F. at the top of the regenerators.

When burning oil, on the other hand, double regeneration, obviously, is impossible. The sensible heat of the products of combustion is greatly in excess of the heat required to raise the air to the temperature of the products of combustion, and very little heat can be taken up by the oil. The balance of the sensible heat from the products of combustion must necessarily be wasted.

Double regeneration with coal gas is not advisable. The hydrocarbon vapors carried in the gas, when brought in contact with the hot checkerwork, are cracked to hydrogen and carbon, the carbon being deposited as soot in the checkerwork. We can see no reason why single regeneration cannot be used with considerable saving, but have no experimental data on this possibility.

Generally speaking, it will not be practicable to build regenerators which would bring about a perfect transfer of heat. In order to demonstrate how far heat recovery could be carried, however, we built an experimental furnace in which the products of combustion leaving the bottom of the regenerators were kept within from 10 to 15° of the temperature of the incoming gas and air. During the test, which was run for 2 days, the products of combustion leaving the furnace were at no time above 85°F. This, of course, was not commercially practicable, as the cost of such a complete saving of the heat was more than the heat was worth. The average stack temperatures of our commercial furnaces are around 175°F., very rarely going over 200°F.

It will be noted that the above discussion applies only to the double regenerative furnace. When firing with producer gas and using only single regenerators, there must necessarily be a loss of approximately 40 per cent of the sensible heat of the products of combustion leaving the hearth, which are wasted to the stack.

To illustrate the possibilities of producer-gas firing, we will describe a set of furnaces which we have designed and built for one of the automobile companies at Detroit, for heat-treating front axles. Three heat treats are required. After the first heating, the axles are allowed to cool in the air by radiation. After the second heating, they are quenched. After which, they are again heated to a lower temperature and allowed to air cool. These furnaces are so designed and laid out that the axles are pushed mechanically through the first furnace and kept moving for a space of about 10-ft. until they reach a temperature

within 90° of room temperature. They then are fed mechanically into the second furnace, pushed through and quenched. A conveyor carries them from the quenching tank to the feeding mechanism of the third furnace, where they receive their final heating and are pushed out the rear end ready for the machine operations. It will be noted that the axles are handled mechanically throughout the process, and after being fed into the first furnace do not stop until the three heat-treating operations are complete. These three furnaces have a capacity of completely heating one front axle per minute. Although the heats are different in each furnace, the three furnaces are duplicates, with the exception of the draft and damper settings to bring about the required temperatures. We will describe more in detail one of these units (see Fig. 295).

The hearth is 5 ft. wide by 14 ft. long. The axles are placed on specially designed cast-iron ways with the forks hanging down. When the furnace is filled with these axles, the axles themselves form a practically solid floor which moves along through the furnace over the ways. Small pieces, such as cam shafts, spiders, spindles, etc., are piled on top of the axles and are carried through the furnace, receiving exactly the same heat treatment as the axles. These small parts are handled by hand between each furnace, as no mechanism has, so far, been designed to handle them mechanically. The gas and air are delivered through the reversing valves to the regenerators at a pressure of approximately 3 in. of water. The four regenerators are placed directly under the hearth. The gas on the inside and the air on the outside. There is one combustion chamber immediately over each pair of regenerators and immediately under one-half of the hearth and extending under its entire length. The products of combustion pass through flues along the sides of the hearth, sweep over the hearth, down through the flues on the opposite side, divide after passing through the opposite combustion chamber, and pass down through the opposite pair of regenerators, through the reversing valves and out the stack. The furnace is reversed on an average of every 15 or 20 min. The products of combustion, while passing over the hearth, are directed by a series of jack arches placed over 2 ft. at right angles to the movement of material over the furnace hearth. A solid division wall, built from the foundation to the hearth, separates the two pairs of regenerators. The furnace is enclosed in a steel jacket with 2½ in. of insulating material between the steel and brickwork.

We might mention that we have built this type of furnace with a muffle to prevent the products of combustion from coming in contact with the steel, the idea of the muffle being to reduce the scaling to a minimum. After several months of comparative tests in running these furnaces with and without the muffle, we concluded that the benefits from the muffle did not warrant the additional expense in construction

and operating cost. To maintain an average hearth temperature of 1,650°, it was found necessary to keep an average temperature in the combustion chamber of 2,550° outside the muffle. The average gas consumption was 264 cu. ft. of gas per minute, the average cubic feet of gas per ton of stock being 22,970. The efficiency of the furnace was 14½ per cent.

With the same type of furnace, running under exactly the same temperature conditions and delivering the same amount of stock, without the muffle, that is, the products of combustion coming in contact with the steel, we found that the average gas consumption was 150 cu. ft. of gas per minute, or 11,500 cu. ft. of gas per ton of stock, with a furnace efficiency of 26 per cent, as compared with 14½ per cent, as stated above.

By furnace efficiency, we mean the total amount of heat put into the stock, divided by the total amount of heat delivered to the furnace in the gas.

From the above comparisons, it will be seen that the cost of operating, which will be discussed later, is very much greater when the muffle is used and the practical results on this kind of stock, with skilful operation, are about the same in both cases. We, therefore, conclude that for this type of work the muffle is not warranted. The muffle furnace, we feel, is not at all practicable unless double regeneration is used, as the heat losses would become enormous without efficient waste-heat recovery. With double regeneration, however, it will be observed, even with the muffle furnace, a furnace efficiency is possible which is very much in excess of the ordinary oil-fired furnace, which rarely exceeds 10 per cent in efficiency.

We find that the temperature of the stock heated in the furnace can easily be kept within a variation of 10 or 15°. By skilful operation, there is no difficulty in keeping the temperature variation within 5°. These results have been obtained over tests of several months' duration.

Advantages of *Regeneration vs. Recuperation.*—With properly designed regenerators, it is possible to recover a much higher percentage of the heat of the waste gases than is possible with recuperators, unless recuperators of very elaborate design are built. Recuperators may be built of metal or refractory material. The advantages of metal recuperators are in preventing leakages and short circuiting. The disadvantages are in their very rapid deterioration, especially at higher temperatures. The disadvantages of regenerators, on the other hand, are that the regenerators must be reversed at intervals of approximately 20 min. to ½ hr., which requires additional mechanism and operating complications. The evidence which we have accumulated to date, however, is distinctly in favor of regeneration and against recuperation, as we have been unable to secure refractories which have the proper heat

conductivity, and, at the same time, can be kept tight through the wide range of temperatures under which they have to operate.

We find that the expense of a furnace with the stock handled mechanically over the hearth, is not justified unless large quantities of stock of the same kind are to be heated. Also if the heating operations are not run continuously for a good many hours, the extra expense of the mechanical furnace is not warranted.

Each particular problem, however, must be studied by itself, as it is impossible to lay down anything more than the most general rules. In a continuous mechanical furnace, such as the front-axle furnaces described, where one axle is charged and one discharged every minute, the front and rear doors must necessarily be open. This, of course, results in quite a loss of heat from the hearth. Intermittent furnaces, built with one door which can be kept closed during the heating operation, show higher fuel economy than furnaces open at both ends.

We have built furnaces similar in principle to the front axle furnace described above, for use in annealing steel for stamping work where the material was maintained at 1,650°F. The costs for this work were practically the same as for the 1,650°F. heat treat on front axles—that is, 40 to 45 cts. per ton. This type of furnace has also been built for carbonizing gears.

We have also applied producer gas with entire success in brazing and for heating enameling ovens.

The following data are the result of continuous tests taken on the above described front axle furnace from April 1 to April 20:

Output of furnace in tons per hour	0.781 ton
Cubic feet of gas per hour	9,000 cu. ft.
Cubic feet of gas per ton of stock	11,500 cu. ft.
Calorific power of gas per cubic foot	127 B.t.u.
Cost of fuel per ton of metal (gas at 3½ cts. per thousand)	$0.401
Cubic feet of gas per minute standby loss (73 cu. ft. at 3½ cts. per thousand)	$0.154
Pounds of stock per hour per square foot of floor space	9.1 lbs.
Percentage of total heat supplied furnace into stock, that is, efficiency of furnace	26 per cent
Percentage of total heat supplied furnace to stack	8 per cent
Percentage of total heat supplied furnace to radiation	66 per cent

In the above test, the fuel supplied the furnace was measured by means of a station meter. This meter measured the gas supplied to two furnaces, the gas being divided between the two furnaces by means of Pitot tubes installed on both furnaces.

The amount of heat that went into the stock was determined from the rise in temperature of the stock and its specific heat. This specific heat was determined by laboratory experiment and found to be 0.12.

In the above data, special attention is called to the calorific power of the gas, which is only 127 B.t.u. per cubic foot. The reason for this low B.t.u. is that the gas was made by gasifying pea coke. This also accounts for the low cost of the gas per 1,000 cu. ft. This gas would be equivalent to ordinary producer gas at 4 cts. per 1,000 cu. ft.

This particular test has been selected out of a great many run to show that a very weak gas can be effectively used in a properly designed furnace, which is contrary to the general opinion that a weak gas cannot be effectively used. The results of these tests check very closely with the average of a long series of tests on gases of different calorific power.

Independently of ours, tests were run on the same furnace over an extended period, and at the same time were run on an oil-fired furnace, to determine the comparative fuel costs of the two methods of heating. The results of these tests, which were made independently of our tests, showed that the cost of producer gas per ton of steel was 44½ cts., as against the cost of oil at $1.48—approximately 3 to 1 in favor of producer gas.

It should be noted again that this cost only applied to the cost of the fuel at the furnace.

We do not pretend to be able to give any costs of heating material with oil. We have run a good many tests and have the results of a great many tests, but there is such a tremendous variation that we prefer to use the figures on oil given us by our clients. We have found that in most cases the tests that were run to determine the cost of heating with oil are run over altogether too short a period. In the work we have done along this line, there have been enormous variations in the quantity used from hour to hour, which leads us to believe that the only way to arrive at a safe estimate is to run the test over a very long period. All of our producer-gas data has been taken over a period of at least two weeks and in most cases is run 2 or 3 months.

It will be noted that the cost data given above are lower than the cost figures which are presented in an earlier part of this Chapter. This difference is due to the difference in the cost of material and labor between the time the data were taken in 1916 and 1917, and the costs as compiled for this paper from work done in 1918.

CLEAN PRODUCER GAS FOR FORGE WORK

One of the most interesting attempts to replace oil with clean cold producer gas has been in connection with drop-forge work

To illustrate some of the cost data accumulated along this line, the author quotes again from the paper read before the Society of Detroit Chemists:

It might be interesting, however, to note the data which were taken on a forge furnace which we built and operated for several months on regular production. This furnace was of the recuperative type with metal recuperators. The hearth was 4 ft. wide by 2 ft. deep. The stock heated was 2-in. round bars. Parts weighing 3.88 lbs. each were made from the heated bars in an upsetting machine.

One hour and 15 min. was required to bring the temperature of the furnace from cold up to forging temperature. When the furnace was filled with stock, from 15 to 20 min. was required to bring the stock to forging temperature. The furnace was run at a capacity of 318 lbs. of stock per hour. The temperature of the hearth varied from 2,300 to 2,400°F. The temperature of stock varied from 1,850 to 1,950°F. On an average, a differential of 450°F. was maintained between the stock and the hearth temperature.

The average of several tests was found to give a fuel cost of $2 per ton of stock heated.

The furnace was operated by putting 10 cold bars into the furnace at a time. This naturally lowered the temperature of the furnace, which, as stated above, required from 15 to 20 min. to bring this stock up to forging temperature. After the stock had been brought up to furnace temperature, there was a surplus of heat available and considerable care had to be exercised that the stock was not overheated.

It was found that better work could be done with this furnace than was done with the oil furnace, because it was impossible to heat the stock too rapidly, that is, the core and outside of the bar were at practically the same temperature. Also the absence of smoke and dirt made the furnace much more desirable.

This work looked very attractive at first, and an immense amount of time and money was spent following it up. Many types of furnaces were built on both the regenerative and the recuperative principles. The outcome of all these efforts, however, can be summed up in this statement: the results in actual operation were not sufficient to warrant the replacing of oil with producer gas on forge furnaces. One very serious objection to the use of producer gas in this connection is that the furnace requires a much more complicated construction than the oil furnace. Forge furnaces of whatever type must be frequently repaired. With the typical oil-fired furnace, an overhead crane can pick it up and set it in an out-of-the-way place where it can be repaired.

In the meantime, a new furnace can be set in its place. With any type of producer-fired furnace which has been developed to date, this is not possible if at the same time there are retained the necessary fuel economies.

Another point which must be kept in mind in this connection is that forge furnaces serving heavy hammers are subject to constant vibration, which will rapidly shake to pieces a furnace of complicated design. In the experimental furnaces where the recuperators or regenerators are placed directly beneath the hearth, it was found, after a few weeks run, that the slag had worked through the hearth and practically stopped up the air and gas passages. Although this point unquestionably can be taken care of, it is very important and cannot be overlooked. As far as can be learned at this date, there never has been a successful small forge furnace developed using clean producer gas for fuel where high production was the important item. Forge furnaces utilizing hot raw gas and running on large work have been developed very successfully, but the small furnaces distributed throughout a shop do not lend themselves to the use of hot raw gas.

CARBONIZING COAL WITH PRODUCER GAS

One of the rather old but very interesting applications of the use of producer gas is in connection with the carbonizing of coal. For many years, it has been common practice to discharge a portion of the hot coke from the retorts directly into gas producers, which heat the retorts. This is still common practice where the maximum yield of gas is required and no market has been developed for coke.

In the last few years, there has been great activity in the development of the by-product coke ovens for the production of metallurgical coke. In many places, a market for metallurgical and domestic coke is found, and in the same market a great demand for gas at certain seasons of the year. This has led to the development of a very flexible combination of the by-product coke oven which can be fired with either producer or coke-oven gas. When the demand for gas is low, the surplus gas found in the ovens is used for firing the retorts. When the demand for coke is low, the coke is gasified in the gas producers for firing the retorts. When the demand for gas and coke are both at their maximum, the producers are run on coal, leaving the total yield of both gas and coke for the market.

SUMMARY

There is no question but that we have reached the period when fuels will never again be as cheap as they have been in the past. The greater the cost of fuel the more economy will be exercised in its use. If the tremendous reservoirs of natural gas had been conserved by some reasonable national legislation and the price regulated to correspond more nearly with actual value, this would have been a never-ending source of tremendous profit to our country.

We now find ourselves facing a tremendous shortage of natural gas in all the older fields, and industries which have been built up on this ridiculously cheap fuel now find themselves embarrassed by having to readjust entirely their processes to the use of some substitute. It is only natural that certain of these industries turn to producer gas. Many mistakes have been made in the past and many more will probably be made in the future by the substitution of this gas; but the fact remains that, in spite of the many difficulties to be encountered, producer gas offers tremendous possibilities in helping to conserve our natural fuels.

Since this Chapter has been written as a warning against overestimating the future scope of producer gas, as well as to stimulate its use where it has a commercial chance of success, a few "dont's" may serve as a fitting close.

Don't install producer gas where it has not already been proved a commercial success, unless you are in position to experiment.

Don't install producer gas until other methods of solving the problem have been investigated thoroughly by an engineer capable of making such an investigation.

Don't employ an engineer who has never made a mistake on producer gas work. He is bound to make some and your plant will probably be his initiation.

Don't lose your nerve the first 6 months of operation. Plants seldom go right off from the start.

A Select Bibliography on Producer Gas Technology*

Books and Pamphlets

ALLEN, HORACE, "Modern Power Gas Producer Practice and Applications." 1908. D. Van Nostrand Co., New York.

*Prepared by C. S. PALMER and originally published in *Proc. Eng. Soc. W. Pa.*, **34** (1918), 347. Revised through 1921.

CLEMENT, JOHN KAY, *and others*, "Essential Factors in the Formation of Producer Gas." **1911.** U. S. Bureau of Mines, *Bull.* **7.**

DAMOUR, EMILIO, "Industrial Furnaces and Methods of Control," tr. by A. L. J. QUENEAU. **1906.** McGraw-Hill Book Co., Inc., New York.

DOWSON, JOSEPH EMERSON, and LARTER, A. T., "Producer Gas." 4th ed., **1920.** Longmans, Green & Co., New York.

FERNALD, ROBERT HEYWOOD, "Recent Development of the Producer-gas Power Plant in the United States." **1909.** U. S. Geol. Sur., *Bull.* **416.**

FERNALD, ROBERT HEYWOOD, *and others.* "Incidental Problems in Gas-producer Tests." **1909.** U. S. Geol. Survey, *Bull.* **393.**

HISCOX, GARDNER DEXTER, "Gas, Gasoline, and Oil Engines, including Producer Gas Plants." **1910.** N. W. Henley Pub. Co., New York.

JUNGE, F. E., "Gas Power." **1908.** Hill Pub. Co., New York.

JUEPTNER VON JONSTORFF, H., "Beitraege zur Theorie des Generator- (oder Luft-) und des Wassergases." **1904.** *F. Enke, Stuttgart* **9,** p. 415. (Ahrens Sammlung chemischer und chemischer-technischer Vortraege.)

KIETAIBL, CARL, "Das Generator Gas; seine Erzeugung und Verwendung." **1910.** Hartleben, Leipzig.

LATTA, MARION NISBET-, "American Producer Gas Practice and Industrial Gas Engineering." **1910.** Van Nostrand, New York.

NAGEL, OSKAR, "Layout, Design and Construction of Chemical and Mechanical Plants." **1908.** Privately printed, New York.

"Mechanical Appliances of the Chemical and Metallurgical Industries." **1908.** Privately printed, New York.

ROBSON, PHILIP W., "Power Gas Producers; Their Design and Application." **1908.** Longmans, Green & Co., New York.

RUSSELL, WALTER M., "Operation of Gas Works." **1917.** McGraw-Hill Book Co., New York.

THORP, FRANK HALL, "Outlines of Industrial Chemistry," ed. 3, **1916.** Macmillan Co., New York.

WYER, SAMUEL S., "Treatise on Producer Gas and Gas Producers." **1906.** "Bibliography of Gas Producers," pp. 277–290.

Iron and Steel and General Metallurgy

CAMPBELL, HARRY HUSE, "Manufacture and Properties of Iron and Steel," ed. 4, **1907.** McGraw-Hill Book Co., Inc., New York.

DICHMANN, KARL, "Basic Open-hearth Steel Process," tr. and ed. by A. Reynolds. **1911.**D. Van Nostrand Co., New York.

FULTON, CHARLES HERMAN, "Principles of General Metallurgy." **1910.** McGraw-Hill Book Co., Inc., New York.

HARBORD, FRANK WILLIAM, & HALL, J. W., "Metallurgy of Steel." **1911.** C. Griffin, London.

HAVARD, FRANCIS THOMPSON, "Refractories and Furnaces." **1912.** McGraw-Hill Book Co., Inc., New York.

HOFMAN, HEINRICH OSCAR., "General Metallurgy." **1913.** McGraw-Hill Book Co., Inc., New York.

INGALLS, WALTER RENTON, "Metallurgy of Zinc and Cadmium." **1903.** McGraw-Hill Book Co., Inc., New York.

LANG, HERBERT, "Metallurgy," **1**, 1911. McGraw-Hill Book Co., Inc., New York.

STOUGHTON, BRADLEY, "Metallurgy of Iron and Steel," ed. 2, **1911**. McGraw-Hill Book Co., Inc., New York.

Glass, Ceramics, Brick, Etc.

BOURRY, EMILE, "Treatise on Ceramic Industries" tr. by A. B. SEARLE. **1911**. Scott, Greenwood & Son, London.

DRALLE, ROBERT, "Die Glasfabrikation." **1911**. R. Oldenbourg, Munich.
"Everything for the Glasshouse." **1908**. H. L. Dixon Co., Pittsburgh.

Fuels, Gases, Etc.

BABCOCK & WILCOX Co., "Steam, Its Generation and use." **1916**. The Company, New York.

HABER, F., "Thermodynamics of Technical Gas Reactions," tr. by A. B. Lamb. **1908**. Longmans, Green & Co., New York.

MARTIN, GEOFFREY, *and others*, "Industrial Gases." **1916**. D. Appleton & Co., New York.

POOLE, HERMAN, "The Calorific Power of Fuels," ed. 3, by R. T. KENT. **1918**. John Wiley & Sons, New York.

WAGNER, FREDERICK HENRY, "Coal and Coke." **1916**. McGraw-Hill Book Co., Inc., New York.

Miscellaneous

"Brown's Directory of American Gas Companies." **1917**. New York.
American Gas Institute, "Gas Chemists' Handbook." **1916**. New York.

Chemical Abstracts and Engineering Index

Chemical Catalog Co., "Chemical Engineering Catalog." **1921**. New York.

RITTMAN, WALTER FRANK, & WHITAKER, M. C., "Bibliography of the Chemistry of Gas Manufacture," compared and arranged by M. S. Howard, 1915. U. S. Bureau of Mines, *Tech. Paper* **120**.

Papers in Journals

Am. Ceramic Soc. Trans.

1900. **2**, p. 38. "Note on the Use of Producer Gas in Burning Bricks," by C. GIESSEN.

1906. **8**, p. 391. "Discussion on Producer Gas and Its Application in Ceramic Work," by S. S. WYER, *and others*.

1908. **10**, p. 396. "A Combination Gas and Steam Power Plant," by G. N. JEPPSON.

1910. **12**, "Notes on Producer Gas," pp. 93, 102, 108, 110, 113.

1913. **15**, p. 444. "Successful Operation of a Continuous Kiln Fired by Producer Gas," by S. GEIJSBEEK.

1914. **16**, p. 585. "Present Status of the Producer Gas Fired Continuous Kiln in America," by R. H. MCELROY & G. R. MUMMA.
A *good* paper. Discussed in **17**, p. 274.

1916. **18**, p. 532. "Results Obtained in Firing Sanitary Earthenware in the Dressler Tunnel Kiln," by C. J. KIRK.
18, p. 862. "Design and Construction of a Producer-gas House for Clay Plants," by A. F. GREAVES-WALKER.

Am. Ceram. Soc. J.
1918. **1**, No. 8, pp. 567–577. "Heat Balance on a Producer Gas Fired Chamber Kiln," by R. K. HURSH.

Am. Drop Forger
1919. **5**, No. 1, pp. 41–44. "Modern Applications of Producer Gas," by E. E. ADAMS.
1907. **2**, pp. 741–898. "A Bulletin on the Care and Operation of Recuperative Benches," by W. A. BAEHR. Much good material on the producer and producer gas.
1908. **3**, pp. 1,007–1,015. "Calculations of Gas and Air Volumes in Furnace Combustion," by J. W. RICHARDS.
1909. **4**, pp. 241–279. "Technical and Mechanical Progress in the Gas Industry During the Past 12 Months," by I. BUTTERWORTH. Gas producers mentioned on p. 260.
1909. **4**, pp. 352–393. "A Pound of Coal," by C. D. Lamson.
1910. **5**, pp. 261–336. "Determination of the Calorific Value and of Operating Conditions, from Analysis of Industrial Gases," by J. M. MOOREGEAD.
See especially pp. 264, 317.
1914. **9**, pt. 1, pp. 543–601. "Carbonization in Bulk—Koppers Ovens," or C. J. RAMSBERG.
See especially pp. 544, 550.
1914. **9**, pt. 1, pp. 178–189. "An Electrical Process for Detarring Gas," or F. W. STEERE.
See especially p. 187.
(There is doubtless much more material in this valuable file but unfortunately it is poorly indexed, and time did not allow the detailed reading which should be given to this subject in this file.)

Am. Inst. Min. Met. Eng. Bull.
1919. Suppl. to No. **153**, pp. 2721–2773. "Gas-Producer Practice at Western Zinc Plant," by G. S. BROOKS and C. C. NITCHIE.

Am. Soc. Mech. Eng. Jour.
1917. **39**, p. 137. "Gas Producer for Bituminous Fuel," by O. C. BERRY. Discussion by G. TAIT, giving remarkable practice of 1¼ lb. poor Coal for 1 hp.-hr. for long period.

Blast Furnace.
1918. **6**, No. 12, pp. 488–492. "Waste Heat from Open-Hearth Furnaces (Producer Gas Fired)," by T. B. MACKENZIE.

Coal Age.
1914. **6**, p. 35. "Producer Gas as a Means for Transmitting Heat."

Eng. Ind. Management.
1920. **3**, No. 20. "The Layout and Operation of a By-Product Producer Gas Plant," by W. H. PATCHELL.

Gas and Oil Power.
1920. **15**, No. 179, pp. 175–178. "Producer Gas for Marine Power." Through a Plant."

Ice and Refrigeration.
1920. **58**, No. 5, pp. 269–271. "The Suction Type Gas Producer," by L. E. SAFFORD.

Iron Age.
1919. **103**, pt. 1, pp. 180–181. "New Coke-fired German Gas Producer."

Le Génie Civil.
1921. **78**, pp. 417–420. "Appareil Chapman pour le brassage des combustibles daus les gazogenes," by J. A. DEGREY.

Met. Chem. Eng.
1917. **16**, p. 695. Producer Gas and Its Industrial Uses." by F. W. STEERE.

Mich. Technic.
1918. **31**, No. 1, pp. 13–17. "Elementary Theory of the Gas Producer," by W. L. BADGER.

Power.
1916. **44**, p. 16. "New Mechanical Gas Producer."
1920. **52**, No. 9. "The Making of Better Producer Gas," by A. C. LISCOM.

Stahl und Eisen.
1911. **31**, part 1, p. 36. "Die Beheizung eines Martinofens mit Koksofengas" (The Heating of a Martin Furnace with Coke-oven Gas).
1912. **32**, part 2, p. 1259. "Ausnutzung mindwertiger Brennstoffe auf Zechen des Oberbergamtsberzirk Dortmund," by O. Dobbelstein.
32, part 2, p. 1477. "Niederrheinische Braunkohle im Martinwerksbetrieb."
See especially p. 1479.
1919. **39**, pp. 1333–1339. "Die Vergasung von Braunkohlen in neuzeitlichen drehort Gaserzeugeon," by K. NEUMANN.
1921. **41**, pp. 325–333, 364–370. "Gewinnung von urteer bei gaserzeugern und seine verabeitung," by KARL LINCK and others.

Note also the special catalogs of the chief manufacturers. Among these are the following:

Chapman Engineering Co., Mt. Vernon, Ohio.
H. L. Dixon Co., Pittsburgh.
Geo. J. Hagan & Co., Pittsburgh.
Alex. Laughlin & Co., Pittsburgh.
Morgan Construction Co., Worcester, Mass.
Smith Gas Engineering Co., Lexington, Ohio.
Tate-Jones & Co., Inc., Pittsburgh.
Wellman-Seaver-Morgan Co., Cleveland.
R. D. Wood & Co., Philadelphia.

CHAPTER XV

WATER GAS

By

A. E. Blake*

INTRODUCTION

The possibilities of water gas as an industrial fuel in this country have been generally overlooked until the present time. It is the object of this Chapter to present such information and suggestions as may be considered best calculated to interest those who are seeking a relatively cheap but thoroughly adequate gaseous fuel supply. The trend of fuel prices is too well known to everyone, and the industrialist is frequently at his wit's end in attempting to cope with the situation.

The use of raw coal, by any means, is becoming condemned more and more generally, especially in technical circles, where conservation and thermal efficiency are watchwords.† The use of raw coal as fuel is already prohibited in certain European countries. Were such a restriction to be adopted in America, assuming adequate by-product coking capacity to be provided, not only would the motor fuel situation be very easy by reason of the benzene and toluene which would be produced, but the use of gas industrially would be very greatly advanced, because of the enormous supply of coke which would be available. This very desirable effect would react upon the petroleum situation and might well release all fuel oil for marine work, for which it is probably better fitted than for any other use.

The author desires to lay stress particularly upon the natural gas situation in industrial regions. A manufacturer formerly accustomed to rely upon natural gas, but now shortly to be deprived of it, is likely to be anxious to find a substitute no more expensive when considered from the efficiency standpoint, and

* Pittsburgh district representative, The U. G. I. Contracting Company, 928 Union Arcade, Pittsburgh, Pa.

† G. M. Darling, *Bureau of Mines Tech. Paper* 178.

which he can make for his own use, and thus free from dependence upon an outside concern for the gas to operate his plant.

Like coal, oil, producer gas, and the electric current, water gas has limitations of technical and financial character. The author believes, however, that these limitations are fewer than in the case of any of the other heating agencies, with the exception of that most ideal fuel, natural gas.

It is the intention to dwell not only on the subject of water gas, but to call attention to mixtures of it with other gases, best adapted for the varying circumstances existing in industrial plants. It is believed that the two-stage gasification of raw bituminous coal, as compared to the one-stage (producer gas) process, cannot fail to interest all those who are considering the use of artificial gas. The two-stage process, to be more fully dealt with below, calls first for the by-product coking of the coal, with consequent recovery of tar and ammonia, and the subsequent generation of water gas from the coke. Instead of very dirty gas of low calorific power and reaction temperature, the two-stage process yields a clean mixture, nearly three times as rich in heat units, and with a reaction temperature equal to that of natural gas.

It is hoped that the following will appeal especially to those whose production and plant conditions preclude the use of producer gas; of regenerative furnaces; or of large cumbersome gas mains, which must be cleaned frequently. Such limitations exist in very numerous instances for reasons wholly aside from simple thermal efficiency, and include such items as quality of the product, space and temperature requirements, temperature control, the character and quantity of labors and many others peculiar to a given plant.

Standard practice for the generation of water gas with only the chief advantageous modifications will have mention in this Chapter. It is desired to lay emphasis upon the fact that there is to be considered a process which is capable of many variations; hence the greater possibility of finding a timely and satisfactory answer to the fuel question by those who have such a problem.

HISTORICAL

In 1780, the action of steam upon incandescent carbon was recorded by Felice Fontana. Enriched water gas was introduced for illuminating in 1830, by Donovan, but his project was short

lived. In 1849, Gillard originated the alternating process of air blow, followed by a steam blow. Patents were granted J. & T. N. Kirkham in 1854, however, for doing the same thing. For the period between 1856 and 1865, the town of Narbonne, France, was lighted by means of water gas and mantles of platinum wire.

What may be termed the modern history of water gas begins in America. In 1873, a water-gas plant was placed in successful operation at Phoenixville, Pa. This development was brought about by J. S. C. Lowe, Strong, and Tessie du Montay. Lowe and Dwight installed a water-gas plant at Essen, Germany, in 1882. A Lowe plant was built in England, at Leeds Forge, in 1888. Water gas was made in Pittsburgh from 1892 until 1919, and formed an important part of the output of artificial gas used chiefly for lighting purposes.

About 1898, C. Dellwick and E. Fleischer modified the process; so that the gases formed during the air blow contain much of their carbon as the dioxide, according to the reaction $C + O_2 = CO_2$. This was done by increasing the force of the air blast and at the same time cutting down the thickness of the fuel bed in the generator. The result is more rapid heating of the fuel bed, due to the far greater amount of heat produced by the complete combustion. These steps enabled them to reduce the customary time of blasting with air from 8 or 10 minutes to 1 or 2 minutes. They also adopted the practice of reversing the direction of steam passage through the bed in order to increase the efficiency of the process. They employed steam at pressures from 150 to 160 lb. per square inch, utilizing sensible heat in the gases leaving the generator, to superheat the steam.*

THEORY OF WATER GAS GENERATION

The simplest conception of a water gas generator comprises a bed of granular carbon supported upon a grate in a retort.

* To show the alertness of the engineering profession in the early days of the gas industry, the following facts may prove interesting:

The Pittsburgh Gas Works Company was formed in April, 1835, by the city treasurer, and the plant was subsequently built and operated by the city. The company was authorized "to construct a suitable works for the manufacture of carbureted hydrogen gas from bituminous coal, for the purpose of public and private illumination." Three Lowe, one-way, 7-ft. diameter gas machines, with a daily capacity of 1,200,000 cu. ft. of carbureted water-gas constituted the recently dismantled plant on Second Avenue, Pittsburgh.

The process starts by ignition of the carbon, and the blowing of air up through it, until the granules become incandescent by oxidation of some appreciable portion of them. The gases leaving the retort during the air blow consist of carbon monoxide and nitrogen.

At the proper degree of incandescence, blowing of air is discontinued and steam is introduced in its place. The steam is decomposed by the carbon to yield equal volumes of carbon monoxide and hydrogen. Twelve parts of carbon react with 18 parts of steam by weight, yielding 28 parts of monoxide and two parts of hydrogen by weight. While the passage of air causes a reaction which liberates heat to the remaining carbon, the passage of steam has the opposite effect, resulting in rapid cooling of the bed and necessitating the passage of more air. The product of the air blow may be used as fuel to generate the steam required. The product of the reaction with steam is water gas.

The following thermochemical reactions will illustrate the foregoing, and they are written in the order in which they occur:

AIR BLASTING

(1) $2C + O_2 = 2CO + 58{,}800$ cal., or 29,400 cal. per gram atom of carbon.

(2) $2CO + O_2 = 2CO_2 + 136{,}400$ cal., or 68,200 cal. per gram atom of carbon.

(3) $CO_2 + C = 2CO - 38{,}800$ cal. per gram atom of solid carbon.

Hence the net heat liberated equals 68,200 − 38,800 or 29,400 cal. per gram atom of carbon oxidized to CO.

STEAMING

(4) $C + H_2O = H_2 + CO - 28{,}800$ cal. per gram atom of carbon.

This reaction occurs while the carbon is at a temperature greater than 1,000°C. (1,832°F.).

(5) $C + 2H_2O = 2H_2 + CO_2 - 18{,}800$ cal. per gram atom of carbon.

Reaction (5) begins to displace reaction (4) at about 1000°C., and increases with decrease in temperature. Below 625°C. no appreciable reaction takes place. So long as there remains a zone above the cooled region which is still about 800°C.,* all except about 9.3 per cent of the carbon dioxide is reduced to carbon monoxide, according to equation (3). This is also an endothermic reaction, and the steam blow must cease promptly when reaction (5) sets in, to prevent waste of steam and the presence of carbon dioxide and water vapor in the product.

* *Compt. rend.*, **130** (1900), 132; **131**, 1,204.

It is evident that, for each gram atom of carbon entering water gas, 28,800 cal. must be supplied to enable reaction (4) to take place. For each gram atom of carbon entering producer gas, 29,400 cal. are made available as sensible heat in the generator. It is also true that the gaseous product of the air blow contains a potential heat of 68,200 cal. per gram atom of carbon

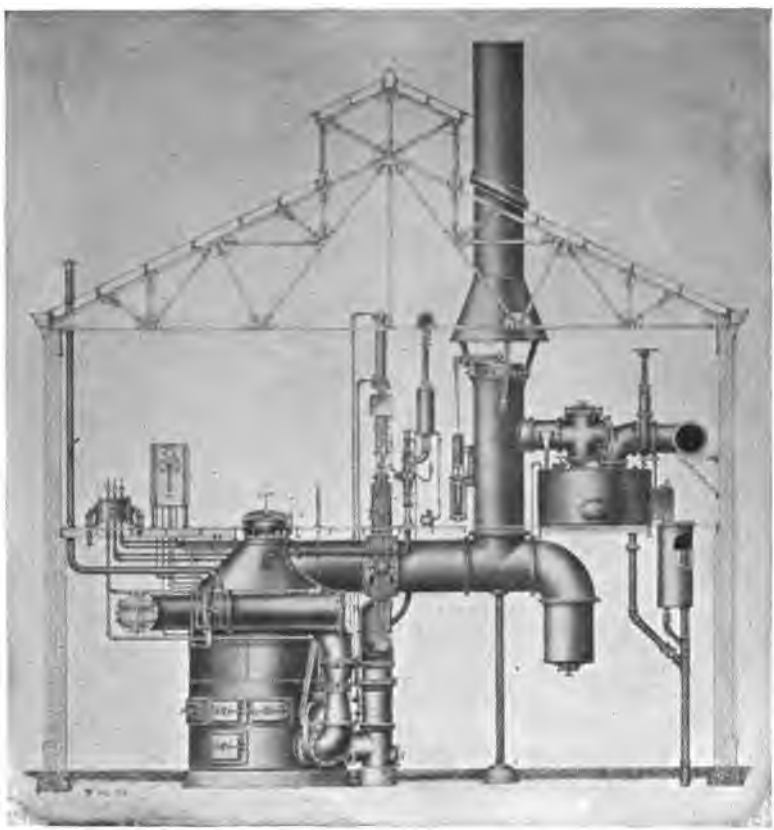


FIG. 303.—The U. G. I. blue gas apparatus. (*The U. G. I. Contracting Company of Philadelphia, Pa.*)

content and it is generally found best to utilize it for steam raising along with the sensible heat of the gases.

The theoretical composition of the water gas by volume is 50 per cent of carbon monoxide and 50 per cent of hydrogen. The calorific value would be 324 B.t.u. gross per cubic foot at 60°F. and standard barometer. Carried out in accordance with

the foregoing, and assuming there are no losses of sensible heat, only enough carbon would need to be burned in the generator to supply the heat requirements of reaction (4) and furnish an adequate potential source of heat for steam raising.

The evaporation of a gram molecule of water from and at 20°C. requires 10,800 cal. This added to the absorbed heat of reaction, 28,800, gives a total heat requirement of 39,600 cal.

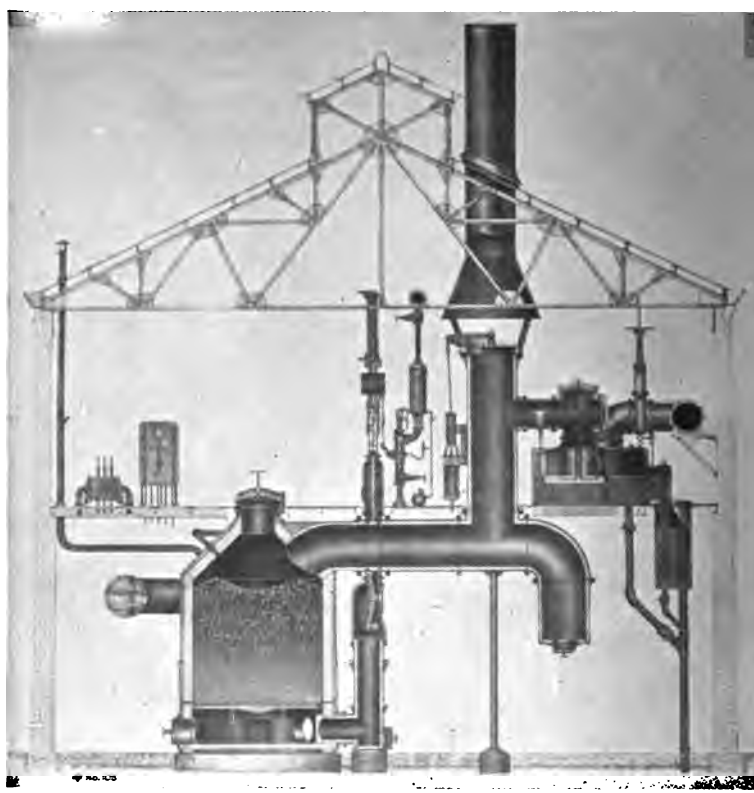


FIG. 304.—The U. G. I. blue gas apparatus, sectional view. (*The U. G. I. Contracting Company of Philadelphia, Pa.*)

PROCESS OF MANUFACTURE

The raw materials of water gas manufacture are steam, supplied at pressures generally greater than 5 lb. per square inch, and some available form of carbon, such as coke, anthracite, petroleum coke, charcoal, or a bituminous coal of a non-coking

character, as, for example, Southern Illinois coal. In the most approved practice, air is supplied at about 1.5 lb. per sq. in.

Figure 303 illustrates a modern water gas set in simple form.

Figure 304 illustrates such a set in cross-section.

The principal features to which attention is called in these figures are blast gases, the generator; its shell; insulated brick lining; grate; clinkering and clean-out doors; charging port; upper and lower exists for gas (the lower takes off water gas

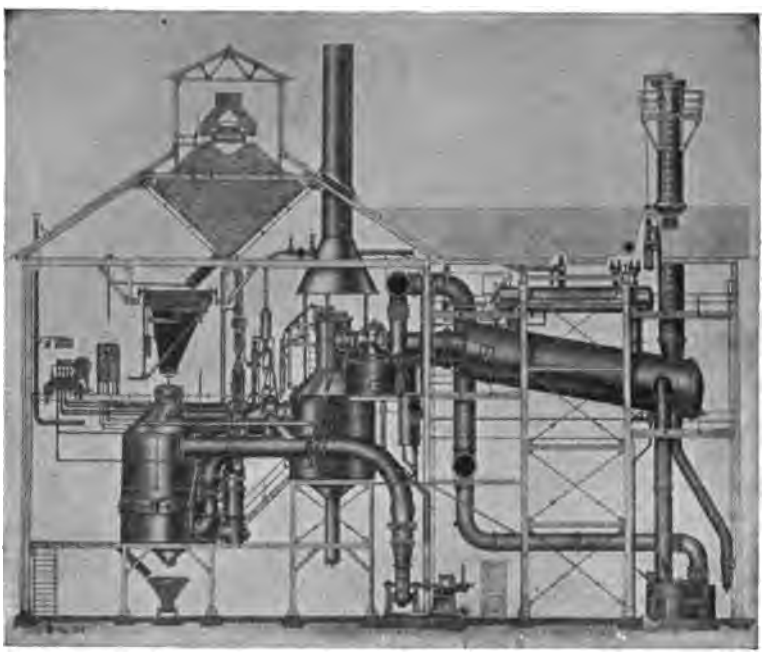


FIG. 305.—The U. G. I. blue gas apparatus with waste heat boiler. (*The U.G.I. Contracting Company of Philadelphia, Pa.*)

only); upper steam inlet; lower steam inlet (shown faintly); air inlet (the venturi); hydraulic control station (on charging floor to left of generator); valves, and their hydraulically operated mechanism, for air, steam, water gas, blast gases, and stack control; and water seal. If one assumes that the external diameter of the generator is 11 ft., this being a common size, he will be able to gain a good idea of the other principal dimensions, including those of the building.

An 11-ft. set is rated at from 100,000 to 150,000 cu. ft. per hour.

compared on the basis of heat units contained, this would be the equivalent of from 33,000 to 50,000 cu. ft. of natural gas of 1,000 B.t.u.

The cycle of the water gas process varies slightly with different installations and from such considerations as kind of fuel, quality of product, and preference of those in charge. A representative cycle might consist of 2 min. for blowing air and 4 min. for blowing steam. It is also customary to blow steam

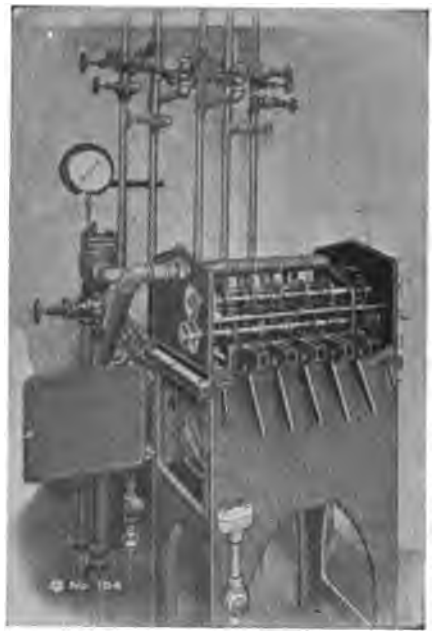


FIG. 306.—The U. G. I. automatic control.

upward through the grate for half of the steaming period, and downward from above the fuel for the remainder of the period.

It is possible, with the use of quite a shallow fuel bed, to blow air rapidly enough to produce oxidation products, mainly carbon dioxide ($C + O_2 = CO_2 + 97{,}600$ cal.). This enables a very rapid heating of the fuel, as mentioned before, and enables the steam blow to follow much sooner than if CO were the product of the air blow, when 29,400 cal. are freed per gram atom of carbon oxidized. Such an apparatus can well be used for supply-

ing the daily requirements of an industrial plant, where 8 or 10 hours of service are required. Since it becomes necessary to "clinker" or clean the grate bars once in each 8 or 10 hours, the time limitation is thus explained. A small gas-holder is required for such service, although it need be only such as to contain the plant requirements for a brief period. A stand-by set can be installed if considered advisable from the standpoint of avoiding losses from occasional shut-down.

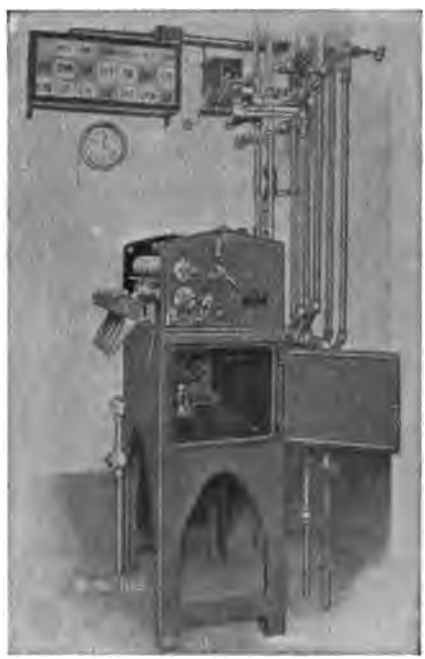


FIG. 307.—The U. G. I. automatic control.

For continuous 24-hr. service, the best practice at the present time calls for the utilization of the sensible heat of the gases coming from the generator, and of the heat of combustion of all carbon monoxide generated during the blasting. Figure 305 shows, in addition to the generator and accessories already named, a combustion chamber under the main stack; a waste-heat boiler and steam drum; boiler stack with stack valve; air blower; fuel bin; fuel car, and ash car. For such an installation, there would be one stand-by generator set, and one boiler can be used when either set is operated (see Fig. 308).

Sufficient steam can be generated in the boiler to supply the needs of the process, including the requirements for power, etc., and there usually will be a surplus of from 20 to 50 lbs. per thousand cu. ft. of gas made.

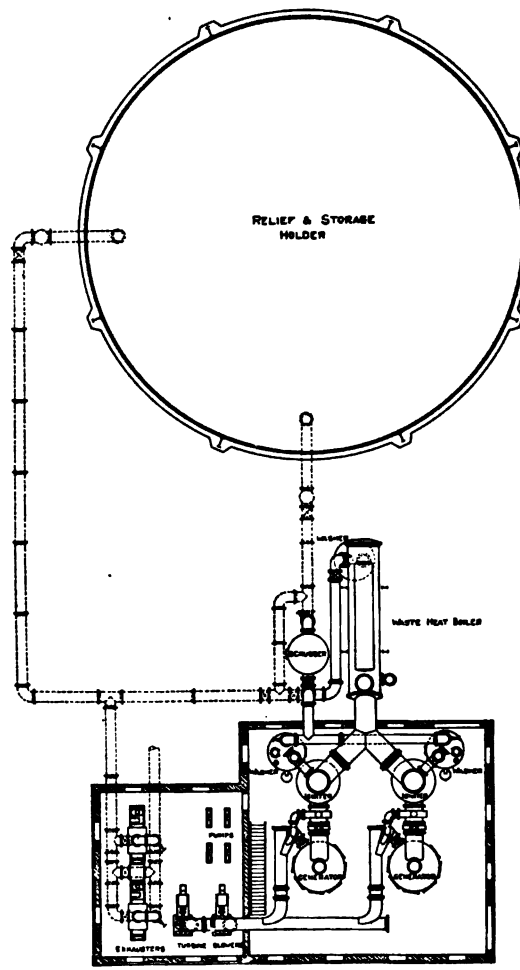


FIG. 308.—Typical layout of blue gas plant with waste heat boiler. (*The U. G. I. Contracting Company of Philadelphia, Pa.*)

Water gas sets are now operated with automatic controls, which operate the valves at the proper time. The automatic control is a most important feature of any water-gas installation.

It is an insurance against ignorance and carelessness, and it does the work which would otherwise be required of a skilled operator. In addition, it enables the apparatus to be operated in shorter cycles, thus saving fuel and increasing capacity.

The control is afforded by a small motor of $\frac{1}{10}$ hp., and consists of a gear train, cams and pilot valves, inclosed in a case outside of which are the dials, run counter, illuminated signal box, and other accessories for setting the apparatus to follow the desired cycle. A glance at the signal box serves to tell precisely what stage of the cycle is taking place at any time. There is an electric alarm and provision for instant shut-down. Every valve and mechanism to be governed in the cycle of operations is connected with the controller by a hydraulic line by means of which hydraulic pistons upon the valves are operated. It is due to this development that a modern gas plant consisting of several sets can be operated by one man who attends to coaling and cleaning fires and has general charge of the apparatus.

Figures 306 and 307 illustrate a controlling station such as has been described.

Figure 308 shows a typical lay-out of a blue gas plant with waste-heat boiler and a holder for relief and storage.

PROPERTIES AND USES OF WATER GAS

As has been shown, the theoretical blue water gas would be 50 per cent hydrogen and 50 per cent carbon monoxide, by volume. Hence 1 cu. ft. would have a calorific value of 324 B.t.u. gross at 60°F., or 316.5 B.t.u. net. The heat content of the average "make" of blue water gas is close to 300 B.t.u. (net) per cubic foot at 60°F.

Two specimen analyses are given below:

CO	43.5
H_2	47.3
CH_4	0.7
CO_2	3.5
O_2	0.6
N_2	4.4
	100.0

B.t.u. per cubic foot = 302 at 60°F. Specific gravity, 0.559 at 60°F.*

* Furnished by Charles J. O'Donnell, of The U. G. I. Contracting Co.

CO	39.1	
H_2	49.3	
CH_4	0.8	
CO_2	6.8	
O_2	0.3	
N_2	3.7	(difference)
B.t.u. per cubic foot = 295 + 2 per cent.*	100.0	

One net ton of good coke or of anthracite will yield about 52,500 cu. ft. of water-gas, or a return in gas fuel of about 8,000 B.t.u. per pound of coke. Assuming the coke contains 10 per cent ash and has a heat content of 13,140 B.t.u. per pound, the efficiency of the process is about 61 per cent.

Because of its carbon monoxide content, water gas burns with a blue flame; hence the terms "blue gas" or "blue water gas," frequently applied to it. The term "water-gas" is commonly applied to carbureted water gas only. The carbon monoxide is also responsible for the fact that the gas is poisonous, as is also the case with producer gas and blast furnace gas. Measures can be taken in the process of making to insure that the gas will have sufficient odor to serve as a warning in case of any leakage. One of the best odorizing agents is phenyl isocyanide.†

On account of the character of fuel used, water gas is very easily cleaned, being free from tar, and carrying only dust which is easily scrubbed out. This is a point in contrast to producer gas from bituminous coal. Water gas is frequently compressed and piped for many miles at high pressure, without the slightest tendency to clog the mains. Thus a very small main can carry great quantities of heat units, compared to the quantities to be sent through a cumbersome and expensive brick-lined main for tarry producer gas. Freedom from tar, and the relative density of the water gas make it admirably adapted to the well known jet-entraining apparatus for utilizing the energy of a gas-jet to entrain and mix the proper amount of air for theoretically perfect combustion. Hence only gas piping is needed in a plant using water gas, and air blowers, air piping and stacks are unnecessary.

The theoretical ratio of gas to air for quantitative combustion is about 1 to 2.1. Hence, 1 cu. ft. of the gas with a calorific

* Average of 15 samples taken at 20-min. intervals. Supplied through the kindness of A. J. HUSTON, Hyatt Roller Bearings Division of the General Motors Co.

† KATZ, S. H., and ALLISON, V. C., "Stenches for Detecting Leakage of Blue Water-Gas and Natural Gas," U. S. Bureau of Mines, *Tech. Paper* **267.**

value of 300 B.t.u. and 2 cu. ft. of air will form 3 cu. ft. of a mixture which has a heat content of 100 B.t.u. per cubic foot. One cubic foot of 1,200 B.t.u. natural gas requiring 11 cu. ft. of air for perfect combustion will form a mixture with a calorific value of 100 B.t.u. per cubic foot. One cubic foot of 150 B.t.u. producer gas, however, requiring 1.3 cu. ft. of air per cubic foot, yields a mixture containing only 65 B.t.u. per cubic foot. Approximately 60 per cent of producer gas is inactive nitrogen; so that there is a vast difference in the rates of combustion of water gas and producer gas. The theoretical reaction temperature of average water gas not carrying sensible heat, is generally placed at about 3,500°F.; whereas that for producer gas is usually given as from 2,400 to 2,900°F.

It is impossible to produce smoke when firing with water gas —a fact of importance to those who must observe smoke ordinaces. Furthermore, there will be produced only the chemiluminescent blue flame, or no flame at all, when using the gas as fuel. This would be a considerable hindrance to its use in the open hearth, or in regenerative glass tanks, as such installations are designed at present. For many classes of welding, water gas is ideal, whereas producer gas is generally useless for that purpose. It is quite common for producer gas supplies to fluctuate materially in calorific value, making it difficult or impossible to secure close temperature control. The heat content of a water gas supply can be maintained very constant, thus well adapting it to such work as annealing, hardening and tempering of steel and other alloys, galvanizing, tinning, etc., as well as for high temperature work, where regeneration is impracticable. One special and time-honored use for water gas is for welding steel tubing and tanks of large size. From the standpoint of fitness, there is no heating operation now carried on with natural gas which cannot be conducted with equal or even greater facility with water gas.

MODIFICATIONS OF WATER GAS AND THEIR USES

Carbureted Water Gas.—The commonest, and before the World War, probably the cheapest artificial gas for domestic use was carbureted water gas, or the blue water gas mixed with pyrolytic products of petroleum.* An increase in the cost of oil,

* On oils for water gas, see Weisser, *Proc. Am. Gas Inst.*, **1916**, i, 198; and Downing, *ibid.*, 588.

which is expected with time, will prove a very great handicap to its use for this purpose.

Figure 309 shows a water gas plant minus a waste heat boiler, but with the additional appurtenances for carburation, consisting principally of a checker chamber of bricks kept hot by

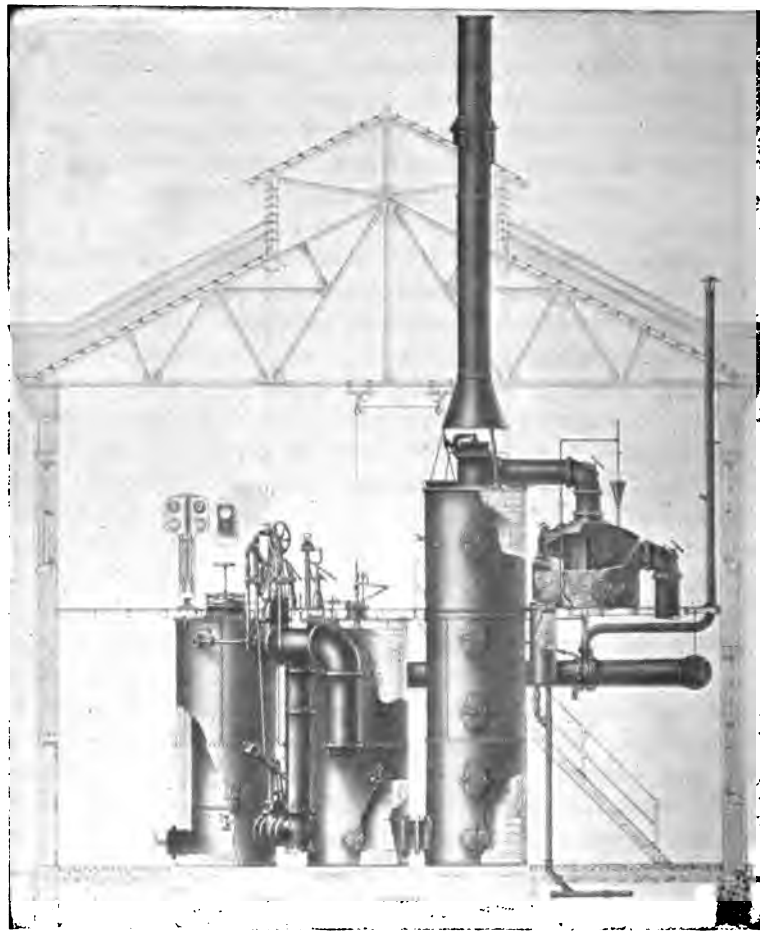


FIG. 309.—The standard double superheater, Lowe water gas apparatus. (*The U. G. I. Contracting Company of Philadelphia, Pa.*)

the sensible heat of the gases passing through and serving to crack the oil which is sprayed toward them; also a superheater of checker brick in which oil cracking products are further heated to form permanent gases. The superheater and carburetor are

kept hot by intermittent combustion of the producer or blast gases from the generator. Formerly, topped Pennsylvanian crude oil was used, but Gulf oil, from which gasoline and kerosene have been removed, is used at the present time.

The addition of oil gas to water gas is entirely unnecessary from the standpoint of domestic heating; but, unfortunately, the earliest use for artificial gas in cities was that of lighting. Welsbach mantles had not appeared, and the fish-tail jet was the commonest burner in use. The added hydrocarbons furnish the required luminosity to water gas flame, thus enabling it to fulfill legal requirements as regards candlepower and to meet those pertaining to calorific power. The reader will bear in mind, however, that the town of Narbonne, France, was lighted for 9 years by blue water gas and platinum mantles. Had the Welsbach mantle been available at that time, it is quite likely that few of the laws in regard to candlepower and calorific value would have been enacted; or, at least, they would be far more tolerant. As it is, the tendency is for fewer and less severe restrictions.* Blue water gas is ideal for the Welsbach mantle, but not for the practically extinct fish-tail burner. The heat units added by way of cracking products will be the most costly in the future; hence, if the matter were rightly and generally understood it seems as though the present hampering restrictions would quickly disappear along with the present enormous demand for gas oil.

The following are specimen analyses of carbureted water gas:

Illuminants	10.7	12.9	12.82
CO	33.4	28.1	28.26
H_2	38.1	21.8	37.20
CH_4	7.6	30.7	18.88
C_2H_6	2.4		
CO_2	3.3	3.8	0.14
O_2	0.7	0.5	
N_2	3.8	2.2	2.70
	100.0	100.0	100.00
Candle power	20.2		22.0
B.t.u. per cubic foot	602.0	659.6	
Specific gravity†	0.676	‡	0.5825§

* F. W. Steere, "Trend of Progress in Gas Supply," *Gas Age*, **45**, 389–390.

† Chas. J. O' Donnell.

‡ C. E. Lucke, "Engineering Thermodynamics," **1912.**

§ W. A. Bone, "Coal and Its Scientific Uses," **1918.**

In addition to the cost of carbureted water gas, precautions are always necessary to prevent it from reaching a temperature below that to which it is reduced in the scrubbing process, in order to prevent condensation of the relatively heavy vapors, the loss of which seriously impairs the candlepower, while tars are formed which clog the pipes.

Combination Coal Gas and Water Gas.—Because of the very attractive possibilities presented, much attention has been directed of late to the possibilities of mixed water gas and coke oven or retort coal gas.

The by-product coke oven is a natural adjunct to any steel plant which operates blast furnaces, its chief function being that of producing the necessary metallurgical grade of coke. Blast-furnace operators know, however, that much of the coke charged to a blast furnace is unsuitable because of its small size. The screenings commonly known as "breeze" are regularly discarded; but small coke up to 2-inch mesh is known to have a pronounced effect in hindering the passage of gases through the furnace burden, and its omission results in appreciably larger production of metal. This small size coke is well suited as a fuel for water gas generation, and a valuable supply of high-grade gas fuel is made available, the uses for which in a steel plant are too well known to mention. The water gas can be mixed with the coke-oven gas if desired. Since water gas is well adapted to heating coke ovens, it is possible to avoid the use of lean coke-oven gas which has from 400 to 500 B.t.u. per cubic foot, thus making it available for the various steel plant furnace operations.

The total gasification of coal can be accomplished in two ways. One is by use of the producer, the technology of which is described in the preceding Chapter. The other is a two-stage process, involving coal carbonizing apparatus and water gas generators. It should pay us to consider the latter case in some detail.

One net ton of bituminous coal will yield about 1,400 lb. of coke, 6 lb. of ammonia (NH_3), 14 gal. of tar, and about 11,000 cu ft. of 570 B.t.u. coal gas, when a portion of the coke (about 350 lb. per ton), consisting of the small coke and breeze, is used to form producer gas for coking.

The 1,050 lb. of coke will produce about 27,600 cu. ft. of 300 B.t.u. water gas. These two yields of gas can be used separately, if desired, or they can be sent to the same holder, where will be

formed a mixture each cubic foot of which will have a calorific value of 375 B.t.u. This mixed product will burn with a slightly luminous flame, though that fact is of small importance in the majority of cases, owing to the superior advantages now realized by the use of modern methods of combustion. The value of by-products recovered is sufficient to meet operating costs.

There are available excellent types of coking units with such capacities as to meet the demands for moderate amounts of gas fuel. Some of these units are of the vertical, self-discharging type, fired by producer gas and reducing the operating costs for labor to a minimum.*

A combination gas plant with a total daily capacity of about 20 tons of coal would represent a minimum size for such an installation. This compares very favorably with the common powdered coal plants of which the minimum efficient capacity is about 80 tons per day.†

Many readers will call to mind the obsolete horizontal retort coke plants which supplied the "coal gas" in our cities 20 years ago and which are still quite numerous. The coke was usually rather difficult to dispose of, and, with development of the water gas process, this coke came to be used to increase the gas output of such plants. Such was the practice in Pittsburgh, even up until 1919. Mention of the foregoing is due, in order to show that there is nothing new in the matter of mixed water gas and coal gas. The vastly superior modern apparatus for making such mixtures deserves the attention of every fuel engineer, however. Allusion has been made to the possibility of legislation against the use of raw coal as a fuel. It would seem that the combination coal and water gas plant is due to have a bright future in case such legislation is every enacted.

Water gas is being added to natural gas supplies in some regions, especially in cold weather, when the demand for fuel is great.

There is no limit to the variety of mixtures which can be had by the use of water gas, coke-oven gas, producer gas, and other gas fuels. Plant conditions will serve to determine the procedure.

* W. V. TURNER, *Gas Record*, **14**, No. 7.

† JOHN E. MUHLFELD, "Powdered Coal," *Proc. Eng. Soc. West. Pa.*, **36**, 243–273.

COSTS

Many interesting demonstrations have been made in the past few years as to the comparative costs of water gas and other gas fuels. For instance, those in charge of the huge gun and shell shop project for Neville Island, in 1918, learned that the cost of 1,000,000 B.t.u. delivered as water gas would have been only about 1.5 cts. greater than the cost of the same quantity of heat delivered as raw producer gas. Water gas was decided upon as the fuel to be used for heat treatment, annealing, shell nosing, and all other proposed heating operations, except open-hearth firing.

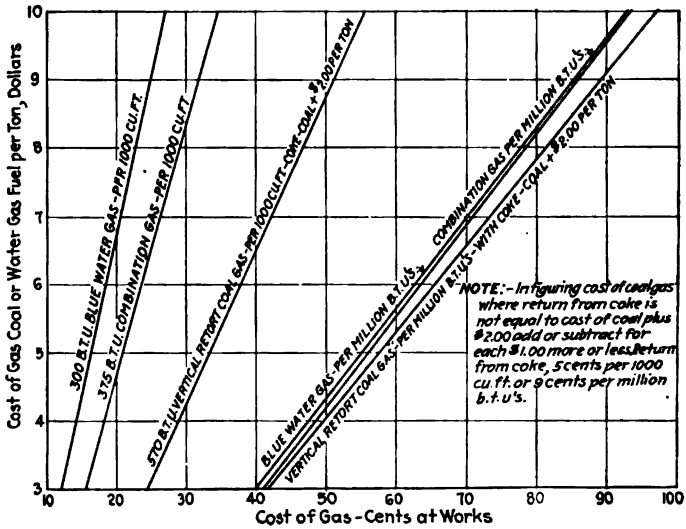


FIG. 310.—Approximate cost of gas at works including plant investment cost at 12 per cent.

The author has knowledge of a proposal by a leading gas engineering concern to a glass company in the Pittsburgh district for the construction of a combination coke-retort water gas plant to furnish the heating equivalent of 2,500,000 cu. ft. of natural gas per day, at an overall cost of $0.362 per 1,000,000 B.t.u. This was in June, 1919.

Figure 310 shows graphically the cost of water gas, coke-retort gas, and the resulting mixture from the two-stage process referred to in the foregoing, at any stated price for coal.* Costs given in this Figure have become considerably less.

Gas Age*, **45, 381.

Figure 311 shows a set of curves which has been prepared to show the comparative heating efficiencies of six common fuels. These are as follows: water gas; carbureted water gas; hot bituminous producer gas; clean, cold bituminous producer gas; clean, cold anthracite producer gas; and fuel oil. The curves have been plotted with reference to the theoretical percentage of a million heat units which a furnace can retain, as compared to that carried away by the flue gases. In all cases, perfect combustion is assumed and, fortunately, perfect combustion is no longer diffi-

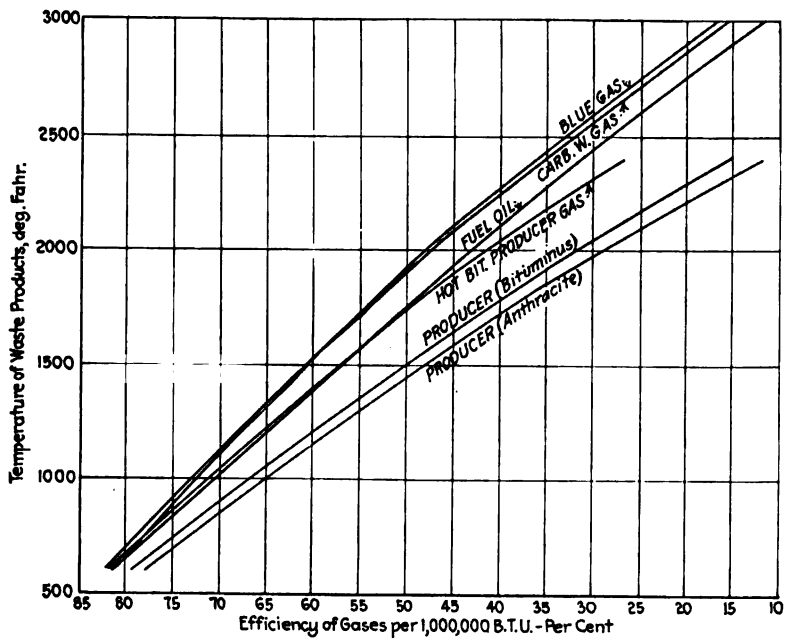


FIG. 311.—Theoretical combustion efficiencies of various gases (perfect combustion).

cult to maintain when the fuel is gaseous. Where inefficient means of firing are employed, it is probable that the relation of the curves shown would be little changed.

Figure 312 shows a series of curves which have been plotted with reference to values taken from those in Fig. 311. They have been developed to show by inspection the comparative cost of heating with four of the fuels mentioned; given the price of coal, coke, or oil, as the case may be. From a consideration of fuel prices, the temperature requirements of his heating units, or the

majority of them; and such factors as uniformity of conditions and of product, a fuel engineer may determine very closely the most advantageous of the four fuels for use in his plant.

The present uncertain supply of natural gas in regions where it has been plentiful until now, together with the certainty that its price will increase; the enforced extra cost of makeshift auxiliary oil-firing equipment, and the oil fuel; and the very evident contrast in the use of the two fuels, are factors which cause an ever increasing demand for artificial gas.

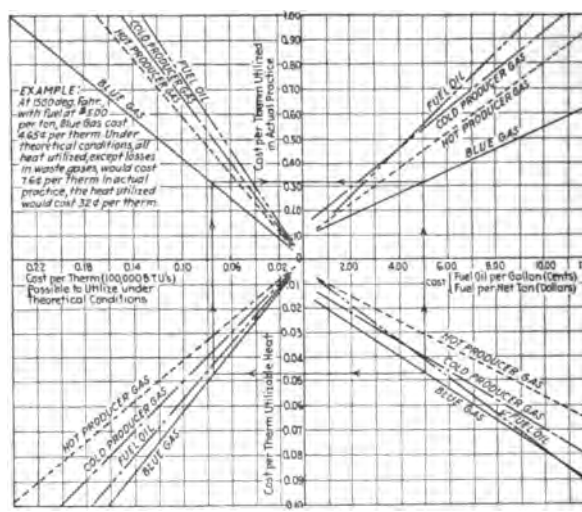


FIG. 312.—Chart showing how efficiency of combustion affects the gaseous fuels and fuel oil in industrial furnaces (working at 1500°F., no regeneration).

ACKNOWLEDGMENTS

The writer is greatly indebted to the officials of The U. G. I. Contracting Co., of Philadelphia, and especially to Messrs. D. J. Collins, J. H. Taussig and Charles J. O'Donnell, for the encouragement and courtesy shown in the matter of supplying many of the facts, and all the illustrations and tables, presented herewith, together with data acknowledged in the footnotes. E. J. Stephany and Robert Young, of the Philadelphia Co., Pittsburgh have supplied facts concerning the making of artificial gas in the Pittsburgh district.

Among the printed sources of information consulted, some of which are referred to in the foregoing, are the following:

BONE, W. A., "Coal and Its Scientific Uses," **1918.**
DOWSON, J. E., and LARTER, A. T., "Producer Gas," **1920.**
FERNALD, R. H., and others, "Incidental Problems in Gas-producer Tests," 1909. (U. S. Geol. Surv., *Bull.* **393.**)
KENT, WILLIAM, "Mechanical Engineers' Pocket-book," **1916.**
MARKS, L. S., "Mechanical Engineers' Handbook," **1916.**

CHAPTER XVI

BLAST FURNACE GAS

By

J. M. Camp and C. B. Francis*

The conservation and use of blast furnace gas follow very closely the development of modern blast-furnace practice, which may be said to have begun with the introduction of the use of hot blast by J. B. Neilson, of Glasgow, in 1828. Apparently, the first attempt to use the gas was made in France as early as 1814, by M. Aubertot, who employed the waste gases from a blast-furnace to heat a cementation furnace and to burn brick. Up to the year 1834, however, it was still the general practice to allow the gases generated within the blast furnace to escape at the top, where they burned in contact with the air, and no use had been made of the waste heat. During that year an attempt was made in England to preheat the blast by passing the air through cast-iron tubes laid across the tunnel head. In 1845, J. P. Budd employed the scheme of drawing off the gases through pipes inserted near the top of the furnace below the stock line, and of firing the stoves, previously coal-fired, with the waste gases; later on he also employed the gases for heating boilers. In both cases he depended on stack draft to draw off the gases from the blast furnace, but in less than 5 years a device for closing the top, known as the cup and cone or bell and hopper, was invented by G. Parry. The bell and hopper made it possible to conserve 90 to 95 per cent of the gas; the only gas which was wasted was that which escaped during the short periods in which the bell was open for dropping the charge into the furnace. Finally, as the value of the gas came to be more and more appreciated, this waste was overcome by means of the double bell and hopper in common use with the modern skip hoist, or by means of a gas seal placed above the bell, as in the bucket hoist.

A third development in the use of the gas, namely, its use in gas engines, is said to have been suggested by B. H. Thwaite as

* Carnegie Steel Company, Pittsburgh, Pa.

early as 1892, and the first power plant of any consequence to be operated with cooled and cleaned blast furnace gas was installed in the fall of 1894 for the Glasgow Iron Company, by Thwaite in conjunction with James Riley of this company, who used the power developed to drive electrical generators. The next 10 years represent a period of rapid development in this use of the gas in Belgium, Germany, Great Britain and France. In the United States, the first large installation of gas engines using blast furnace gas exclusively was made by the Lackawana Steel Co. about 1903. This installation consisted of eight two-cycle engines of 1,000 hp. each, the units being connected directly to electric generators. In 1906, the Carnegie Steel Co. installed two four-cycle units of 2,000 hp. each at their Edgar Thomson works, for blowing air to the furnaces, and shortly afterwards other installations were made at the McKeesport, Carrie and Duquesne furnaces.

After the introduction of the gas engine, no very important developments in the use of the gas have been made, and the interval from 1895 to 1920 has been devoted, especially in the United States, mainly to the development of more economical and efficient means of cleaning and burning the gas. Indeed, the events of 1918 and 1919 appear to indicate a narrowing of the field of application of the gas to its use in stoves and boilers. The development of the steam turbine, especially the turbo-generator, coupled with improvements in boiler construction and design and appliances for burning this gas, has made it possible to obtain a thermal efficiency of 15 to 17 per cent from the gas consumed in this way, as against a thermal efficiency of 19 to 22 per cent when it is used in gas engines. This fact, along with the numerous advantages which the turbine installation has over the gas engine, has led some operators to supply their new power requirements with the turbine installation; and in one or two instances, where local conditions favored the change, gas engines employed for generating electrical power have been replaced by turbo-generators using steam generated by the gas burned in the new type of boiler.

CONDITIONS AND PRINCIPLES BY WHICH BLAST FURNACE GAS IS PRODUCED

From this brief outline of the history of the development in the use of blast furnace gas, it is apparent that the modern

blast furnace has a double function to perform, namely, that of iron smelter and gas producer. A brief consideration, then, of the blast furnace in the rôle of gas producer should not be out of place. The size, form, operation and general principles of and the materials used in the blast furnace have been described at length in the literature on that subject,* so, for want of space, these topics cannot be more than mentioned here. It may be pointed out, however, that the process of making pig iron is a continuous one in which the principle of counter-currents is employed throughout. The efficient operation of the furnace therefore requires that a continuous supply of air be admitted above the hearth near the bottom and that the solid materials, consisting of ore, fuel and flux, be charged at regular intervals through the top. Of the solid materials, the ore consists of hematite, Fe_2O_3, or magnetite, Fe_3O_4, gangue and moisture; the fuel, usually in the form of coke, of carbon, ash, a little volatile matter and moisture; and the flux, usually limestone, of calcium carbonate, $CaCO_3$, and impurities. As a rule, the manner of charging these materials is such that they are deposited in the top of the furnace in alternate layers of coke or ore-coke mixtures and ore-limestone mixtures. As these materials pass downward through the furnace, the ore and limestone lose their identity completely, the former being reduced gradually and the latter decomposed; but the larger portion of the coke reaches the bottom of the furnace unchanged. It will be surmised, then, that gas-producing reactions and changes are taking place at practically all levels in the furnace.

Gas-producing Reactions in the Hearth and Bosh.—The gas-producing reactions may be considered as beginning in the hearth and bosh. The chief reactions here are brought about by blowing air, preheated to temperatures varying from 400 to 750°C., and divided into 10 to 16 jets by means of tuyeres symmetrically arranged about the upper circumference of the hearth, against the column of incandescent coke that extends to the bottom of the hearth. This condition results in the oxygen of the air instantly combining with the carbon of the coke to form carbon monoxide, according to the exothermic reaction, $2C + O_2 =$

* See especially STOUGHTON's "The Metallurgy of Iron and Steel," **1911**; JOHNSON's "Blast-furnace Construction in America," **1917**; JOHNSON's "The Principles, Operation and Products of the Blast Furnace," **1918**; and CAMP and FRANCIS, "The Making, Shaping and Treating of Steel," **1920**.

$2CO + 29{,}160$ cal. This action may be an indirect one, carbon dioxide being first formed, but the final result is not affected. The water vapor in the air, which in summer may amount to as much as 10 grains per cubic foot, also reacts with the carbon, forming carbon monoxide and hydrogen, according to the endothermic reaction, $C + H_2O = CO + H_2$. The result of these reactions is to give a temperature in excess of 1,700°C. The hearth reactions, by which the oxides of the metalloids are reduced and sulphur is eliminated from the bath, also produce carbon monoxide. They may be represented thus:

1. $MnO + C = Mn + CO$;
2. $SiO_2 + 2C = Si + 2CO$;
3. $P_2O_5 + 5C = 2P + 5CO$;
4. $FeS + CaO + C = Fe + CaS + CO$.

Any ore or iron oxide that may by any chance reach the region of the bosh or hearth is reduced directly by carbon, giving carbon monoxide, thus:

1. $Fe_2O_3 + 3C = 2Fe + 3CO$;
2. $Fe_3O_4 + 4C = 3Fe + 4CO$;
3. $FeO + C = Fe + CO$.

The gases, which now consist of the inert gases of the atmosphere, carbon monoxide and a little hydrogen, begin a rapid journey up through the interstitial spaces of the descending stock. The great speed of the gases up through the stack can be appreciated when it is pointed out that the total cubical content of the modern furnace is about 25,000 cu. ft. and that the volume of the blast will generally approximate 45,000 cu. ft. of free air per minute. When it is considered that this volume is increased three- or four-fold under the conditions of temperature and pressure prevailing within the furnace, and that the greater portion of the space is occupied by the solid and liquid materials, it will be seen that the passage of the gases from the tuyeres to the top of the furnace can occupy but a few seconds.

Gas-producing Reactions in the Stack.—Except to give up their heat to the descending materials, causing the fusion of the iron and slag already formed and possibly the final reduction, by direct action of carbon, of some iron oxide not completely reduced in the upper zone, the gases undergo no change until the level corresponding to about 900°C., some 15 to 20 ft. above the top of the bosh, is reached. Here the calcination of the limestone takes place, according to the endothermic reaction,

$CaCO_3 = CaO + CO_2$. Below this level any carbon dioxide that might occur in the gases would react immediately with carbon to form carbon monoxide. The calcination of the limestone, together with the cooling effect of the colder descending stock, lowers the temperature to such an extent that carbon dioxide can exist in equilibrium with solid carbon. From this point onward the composition of the gases is continually undergoing changes, for the carbon monoxide may now act as a reducing agent. The reactions are confined entirely to those between the iron oxides or iron and the carbon oxides or carbon. The reactions that represent the reduction of the ore are as follows:

Direct reduction:
1. $3Fe_2O_3 + C \rightarrow 2Fe_3O_4 + CO$;
2. $Fe_3O_4 + C \rightleftarrows 3FeO + CO$;
3. $FeO + C \rightleftarrows Fe + CO$.

Indirect reduction:
1. $3Fe_2O_3 + CO \rightarrow 2Fe_3O_4 + CO_2$;
2. $Fe_3O_4 + CO \rightleftarrows 3FeO + CO_2$;
3. $FeO + CO \rightleftarrows Fe + CO_2$;
4. $2Fe_2O_3 + 8CO \rightarrow 4Fe + 7CO_2 + C$.

It will be observed that reactions 2 and 3 in each set are reversible and are not to be considered as going to an end in either direction. If all the substances involved were confined so that they would remain in the field of action, they would result only in the establishment of equilibrium between the solid phases, carbon, iron and ferrous oxide, and the gas phases, carbon monoxide and carbon dioxide; and the extent to which the iron oxides would be reduced would depend upon the temperature and the relative amounts present of carbon and carbon monoxide in the case of direct reduction, or carbon monoxide and carbon dioxide in the case of indirect reduction. In the blast furnace these reactions can only tend to produce equilibrium: first, because the temperature is constantly changing, the solid materials dropping to levels of higher and higher temperatures and the gas rising to levels of lower and lower temperatures; second, because the rapid upward flowing of the gas combined with the downward movement of the stock does not give time for the establishment of equilibrium; and, third, because the rapid removal of their gaseous products tends to cause the reactions to proceed to an end. However, this tendency toward equilibrium is so pronounced as to bring about a fairly constant volume relation between carbon monoxide and carbon dioxide in furnaces that

are working smoothly and regularly and with uniform materials. Under such conditions and with the practice most generally followed, this ratio is about two volumes of carbon monoxide to one of carbon dioxide. This relation may be disturbed by a change in the coke consumption, by a change in blast temperature, by a change in the amount of air blown, or by a slipping of the stock in the furnace.

It may be well to note that the gas volume per ton of iron and the calorific value per cubic foot of gas increase with the rate of coke consumption, but that an increase of the fuel consumption decreases the output of iron. Heretofore the chief function of the blast furnace, as it appeared to the furnacemen, was to produce pig iron. With this attitude, it has been their aim to make iron of a quality best suited for the purpose intended, and, at the same time, as cheaply as possible and in as large a quantity as possible. Now, it so happens that, aside from the careful selection of raw materials, the next most important factor to be watched in operating a furnace to produce iron most cheaply is the fuel consumption. The furnacemen, then, have endeavored to reduce the amount of fuel used to a minimum and have given little consideration to the quantity or quality of gas produced. It is doubtful, however, if this attitude will continue, for, with the advent of the by-product coke process, which, through the by-products recoverable, tends to cheapen coke, and the increasing desirability of producing a constant supply of gas, the question of fuel consumption per ton of iron produced may assume less importance.

The Source of Moisture in Blast Furnace Gas.—Passing upward beyond the zone of reaction, the gas still has an important function to perform, namely, that of drying the stock. The vaporization of this water, which, with soft ores, may amount to 14 per cent of the total charge, tends to lower the temperature of the gas; but it still retains sufficient sensible heat to maintain its temperature above 150°C., the usual temperature being between 200 and 300°C. The top temperature varies mainly with the driving and the speed of combustion at the tuyeres, but is also affected by the distribution of the stock, and in other ways. The amount of moisture which the gas now carries depends upon the moisture in the materials of the charge. With Missabe ores the moisture content of the gas varies from 25 to 50 grains per cubic foot.

the bluish flame characteristic of carbon monoxide. Being a lean gas, it burns somewhat slowly, hence either burners that will mix the gas with the proper quantity of air prior to combustion or long combustion chambers are necessary to secure the greatest efficiency. The rapidity of combustion can be increased by preheating the gas. Mixed with air, the gas is explosive over a rather wide range of proportions, but the most explosive mixtures call for equal volumes of gas and air. These properties, however, offer but slight difficulties in the utilization of the gas, and the handling of it would be a comparatively easy problem if the gas leaving the furnace did not carry with it the flue dust previously described. Although for many years the gas was used in stoves and boilers without any cleaning except that secured through deposition in the gas mains, modern practice requires that at least a portion of the dust be removed before the gas is burned.

STAGES IN CLEANING THE GAS

In modern practice the cleaning of blast furnace gas is carried on in three stages, known as preliminary cleaning, primary cleaning, and final cleaning.

The Dust Catcher.—In the preliminary cleaning, the gas is conducted from the furnace top through a downcomer to one or more dust catchers, located at a convenient place near the bottom of the furnace. Various types of dust catchers have been developed. Essentially they are large brick-lined cylinders, several times larger in diameter than the downcomer. At the bottom they are provided with a dust pocket, usually in the form of an inverted cone, in the apex of which is placed a valve for removing the deposited dust at intervals as desired or necessary. In one type the gas enters the catcher through a pipe inserted vertically through the center of the top so as to extend a few feet into the cylinder, and leaves by way of one or more exits on the circumference, also located near the top. In another type the gas enters tangentially through an opening on the circumference and leaves by way of a pipe extending upward through the center of the top, thereby facilitating the deposition of the dust by centrifugal force. In a modification of this type the gas is admitted tangentially near the top and is forced to leave through a central pipe projecting deep into the dust catcher. However, the basic principles of separation of the dust in all these appar-

atus are the same, namely, a sudden change of direction in the flow of the gas and a quick decrease in its velocity, due to their having a greater cross-sectional area than the downcomers and gas mains. Attempts have been made to increase the cleaning efficiency of the dust catcher by introducing water in various ways; but the results did not justify the extra expense connected with handling wet dust and of operating the catcher wet, so that dust catchers are now always operated dry, which method eliminates all operating costs and makes it easier to handle the accumulated dust. Occasionally the gas is conducted through two dust catchers in series. From 50 to 70 per cent of the total dust carried out of the furnace is deposited in the modern dust catchers.

Uses of Raw Gas.—The gas after leaving the dust catcher still contains from 3 to 5 grains of dust per cubic foot, and is known as raw gas. It may be, and still is to a considerable extent, used in stoves and boilers, but its use is conducive to low efficiencies. In stoves the use of raw gas soon results in the deposition on the brick work of a heavy coat of dust, which fuses and penetrates the brick, thus preventing the absorption of heat, and requiring constant attention in order to keep the material removed. In boilers the drop in efficiency due to the dust is not so marked, some operators claiming as high an efficiency with raw gas as with wet cleaned gas. This is due to the fact that with raw gas the sensible heat of the gas is retained, which adds to the heat value of the gas. However, it has not been shown that this gain more than offsets the insulating effect of the deposits of dust on the tubes, which usually must be cleaned about every 24 hrs. by blowing the dust off with a steam or air lance. The gain by the use of clean gas appears in continuous operation of the boilers and in the saving in labor required for cleaning.

Primary Cleaning.—In order to overcome the disadvantages connected with the use of raw gas and secure the greatest economy from burning the gas in stoves and under boilers, it has been found necessary to reduce the dust content of the gas to less than 0.3 grain per cubic foot. To accomplish this result, various devices and systems have been employed. From the dust catcher, then, the gas passes through a large gas main, equipped with dust pockets and valves for the removal of deposits of dust, to a primary cleaning plant. Here the mode of treatment varies according to the opinions of the operators as to the merits of the various devices and systems. In general, there are two methods

for primary cleaning; *viz.*, dry cleaning and wet cleaning. Dry cleaners are of two types, the whirling and the filtering. There are three general types of wet cleaners: (1) the impinging washer; (2) the mechanical washer; and (3) the tower scrubber.

The Whirlers.—As with the case of dust catchers, the basic principles of whirlers involve sudden changes in direction of the flow of the gas, a reduction in its velocity, the production of centrifugal force and the separation of the dust by gravity. Many different apparatus employing these principles have been developed in the United States, the most important of which are the Brassert-Witting, the Roberts, the Kennedy, and the Dyblic.

The Dry Filter.—Experience has shown that whirlers cannot be depended upon to clean the gas from furnaces using much fine ore to the degree desired for use under boilers and stoves, the dust content of the gas, after passing through the whirlers seldom being lower than 1 grain per cubic foot. Other principles that may be employed to clean the gas are deposition, electrical precipitation, and filtration. Of these, only filtration through textiles, as in the Halberger-Beth and Smith-Bayley systems, had been employed extensively on blast-furnace gases prior to 1920; and these systems are subject to the objection that, if the gas is not cooled considerably, it will burn or char the textile, and, if cooled too low, the moisture in the gas wets the textile and clogs the filter in a short time. In 1917, however, F. E. Kling and Luther B. Weidlein patented a device, employing the filtering principle, by means of which they are able to overcome these drawbacks to dry cleaning by filtration. Essentially, their scheme consists of forcing the gas upward through filtering mats of steel wool held between two strong steel nettings.

The first cleaner, large enough to clean all the gas from one furnace, was completed early in 1919. It is a large rectangular structure built of reinforced concrete, having walls about 15 in. thick. The entire structure is supported on concrete piers at a height of about 15 ft. above the ground, and is divided into eight distinct compartments. Each compartment contains a set of two filtering mats of moderate thickness and different compactness, arranged one above the other, or a single mat of much greater thickness and varying compactness. The gas from the dust catcher enters, through different branches, at the bottom of each compartment, passes upward through the filters, and

leaves through openings near the top of the structure as clean gas. The filters in each compartment are attached to a vertical rod, connected to an electric motor located on top of the cleaner, in such a way as to impart a vertical motion to the rod, thus shaking the filter at regular intervals of time. This shaking causes the dust that has collected on the underside of the filtering mats to drop into a dust pocket below, which is large enough to hold the accumulation of about 2 days. When two mats are used, the upper mat is in two parts and is placed above a shed which prevents the loose dust from falling upon the lower mat. During the time the filtering mats are being shaken, the gas is shut off from the compartment, the outlet being closed. The operation of the cleaner is entirely automatic. The power required to operate the cleaner is said to be less than 3 hp. and the cleaning efficiency 90 to 97 per cent, the dust content of the clean gas varying from 0.1 to 0.4 grain per cubic foot. The average drop in temperature of the gas on passing through the apparatus is about 35°F., and the back pressure on the furnace is equivalent to about 3 in. of water.

Wet Primary Cleaning.—Of the three types of wet cleaners, the tower scrubber has proved the most satisfactory. The impinging type, which depends on directing the gas at high velocity against a surface of water, thus impelling the dust particles into the water, while the gas changes direction and flow, causes the hot gas to become so moisture-laden as to interfere seriously with the proper combustion of the gas later. Mechanical washers generally consist of a high-speed motor-driven rotor revolving in a shell, into which water is injected while the gas is passing through the shell. The water is thus broken up into a spray and brought into intimate contact with the gas. While these contrivances are efficient in cleaning the gas, their capacities are low and the costs of installation and operation are high. All these disadvantages are overcome in the tower washer, of which there are two kinds, namely, the baffle or hurdle tower and the spray tower. In the first-mentioned the water is introduced at the top through nozzles and allowed to fall by gravity over hurdles and baffles or wooden grids while the gas flows upward through the tower; in the other the water is introduced through vertical nozzles discharging upward. For cleaning furnace gas in the United States the latter type is the one used most often. A brief description of this tower follows.

The Spray Tower.—A very efficient example of this tower is the one known as the Duquesne tower, sometimes called, also, the Diehl scrubber. This tower is about 80 ft. in height and 12

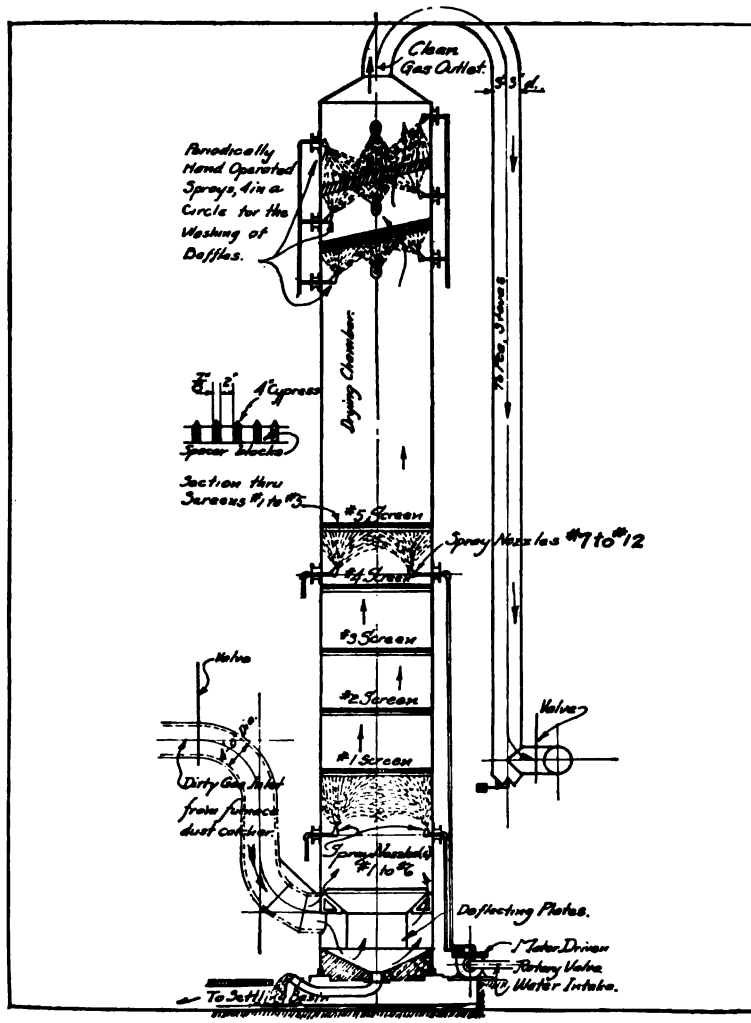


FIG. 313.—Modified Duquesne gas washer.

ft. in diameter. Internally, the central portion of the tower is provided with five sets of double screens, placed at intervals of 6 ft. 10 in. apart. Under the bottom and top sets of screens are

distributed seven nozzles, the feed water for which, delivered under a pressure of 35 lb., is controlled by two valves outside of the tower. These valves have a revolving core, electrically operated, which successively blocks off the openings to the different nozzles, thereby temporarily stopping the flow of water in and creating an area of low pressure above each nozzle in turn. By this means the water is broken up into fine drops, and the gas, which rises through the tower at the rate of about 4 ft. per second, is compelled to follow a zigzag course through the rising water jets and the descending spray, thus bringing it into intimate contact with the water. As this scrubber usually is operated, it cleans about 25,000 cu. ft. of gas per minute, and uses about 815 gal. of water. The gas is cooled below 90°F. at all times, the actual temperature being from 5 to 10°F. above that of the ingoing water. The moisture content of the cleaned gas is about 0.5 grain above that at its saturation point. The average dust content of the clean gas is 0.2 grain per cubic foot. The passage of the gas through the tower reduces the pressure by 2½ in. of water; that is, when the pressure in the receiving main is about 10½ in., that in the clean gas main is about 8 in. In a modified form of this cleaner the height of the tower is increased to about 100 ft., and the upper portion, in the top of which is placed a set of baffles for changing the direction of flow of the gas, is used as a drying chamber.

Uses of Cleaned Gas.—The chief uses of cleaned blast-furnace gas, namely, its application under blast furnace stoves and boilers, have been indicated. In former time the requirements of the furnace itself called for the greater portion of the gas; but, with modern improvements in using the gas, at least half of the gas produced is available as surplus. Where the furnace is operated in conjunction with steel works, this surplus is employed for the generation of electrical power, either through the medium of the gas engine or the steam-boiler turbine combination. Where the furnace plant is operated independently of the steel works, the surplus gas is preferably disposed of as electric power for public consumption. But the stringent requirements as to continuity in that service causes the furnace operator to hesitate before entering into contracts of that kind. For general heating purposes the gas is not a very desirable fuel, because its low heat value per unit volume makes its transportation costly and restricts its use to adjacent and low temperature operations.

However, realizing the enormous potential value of this surplus gas, a few individuals have attempted to make it available for general use. One such attempt consisted of enriching the gas by passing it through hot coke, thus reducing its moisture and carbon dioxide contents to combustible gas, but this plan does not appear to have been practicable. Attempts to mix the gas either with producer gas or by-product coke-oven gas have been more successful. In a few instances the gas has been employed successfully for heating by-product ovens instead of the regular oven gas. It appears that the surplus gas is most satisfactorily disposed of as electric power generated at the plant.

Final Cleaning.—When the gas is to be used in gas engines, the primary cleaning must be followed by a final cleaning; for experience has shown that the best practice has resulted when the dust content of the gas and air does not exceed 0.005 grain per cubic foot of explosive mixture. Since the average dust content of air about a plant is 0.002 grain per cubic foot, this statement implies that the dust content of the gas should not exceed 0.008 grain per cubic foot. Another condition is that the gas be cooled to or below atmospheric temperatures.

Types of Final Cleaners.*—As in the primary cleaning, the final cleaning may be either dry or wet. Dry cleaning depends upon three principles, namely, deposition, electrical precipitation, and filtration. The use of these principles is exemplified by the following apparatus: The Howard dust separator depends upon the deposition of the dust, while the gas is moving at low velocity, on a series of steel plates, placed about 2.5 in. apart, and confined in a chamber of brick or steel. In the Cottrell system, the efficiency of which for fuel cleaning has not been fully demonstrated, the raw gas is electrolyzed by discharging high-tension direct current into it from a suitable metallic electrode extending axially through a vertical pipe of iron or steel. By this means the highly charged dust particles are deposited on the pipe, and, by breaking the circuit at intervals, the adhering dust is made to fall into a hopper below. The Halberger-Beth and the Smith-Bayley systems, which are used for both primary and final cleaning, employ the filtration principle, the first using bags in a manner similar to that employed in zinc works to recover zinc dust, and the second passing the gas through travelling belts composed of canvas or other suitable textile. The wet washers

* See also GELLERT, *Iron Trade Rev.*, Feb. 13, **1919.**

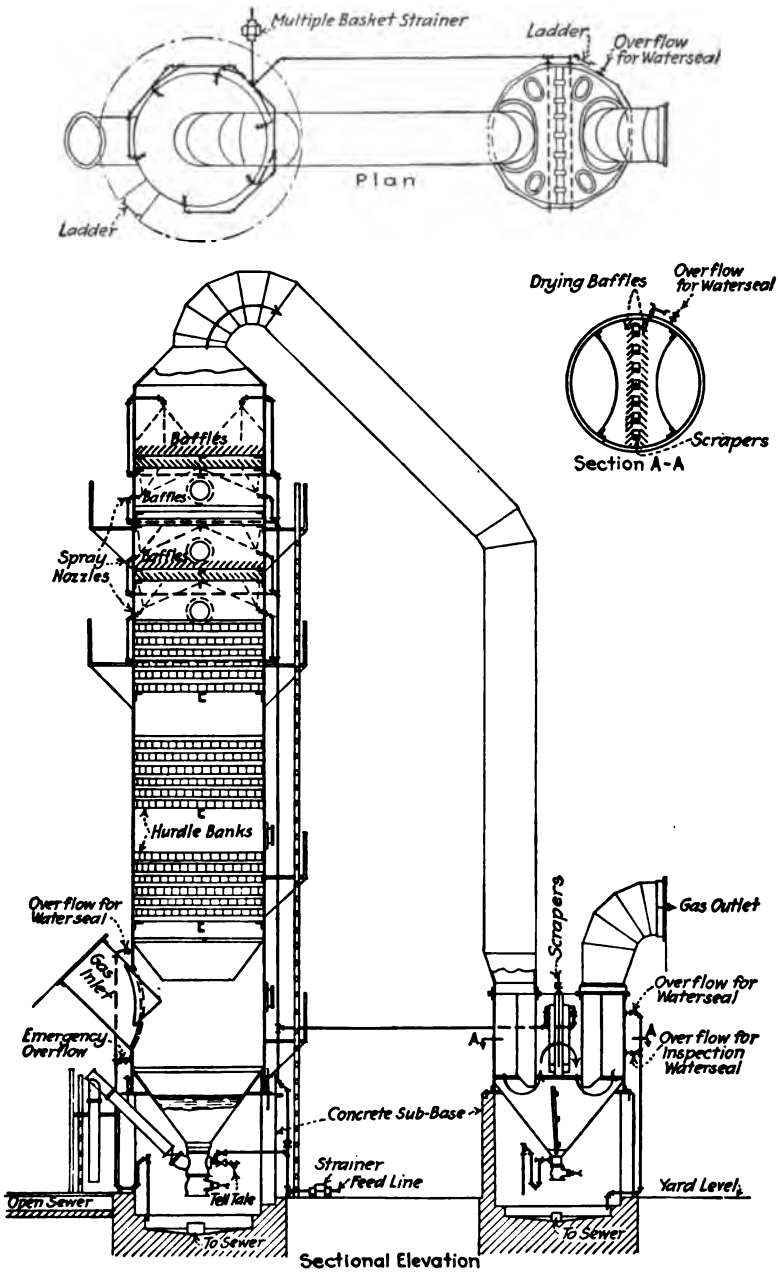


FIG. 314.—Typical general arrangement of Brassert gas washing and drying system.

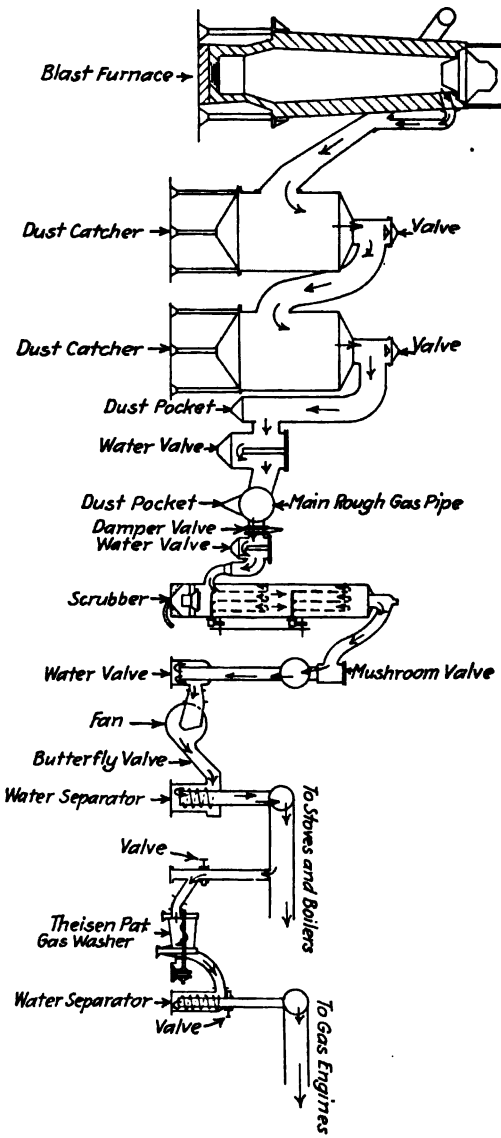


FIG. 315.—Diagram showing route of gas from furnace through gas cleaning plant to boilers, stoves, and gas engines.

all depend on converting water mechanically into a spray, and then forcing the gas to pass through this spray, the flow of the two fluids, with but one exception, being directed in accordance with the principle of counter-currents. Representatives of these washers are the Sepulchre gas washer, the Reco centrifugal gas

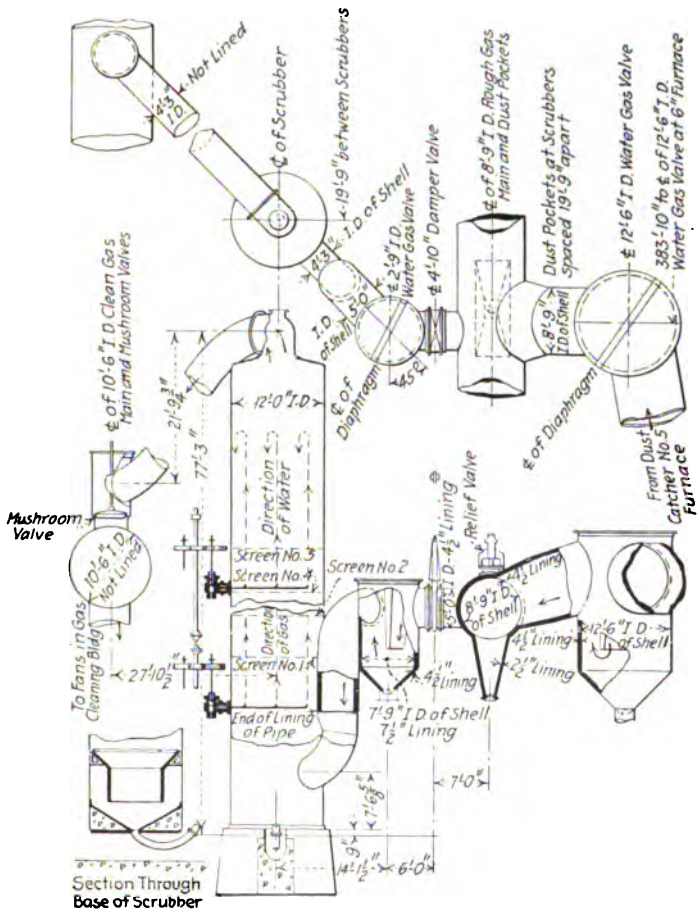


FIG. 316.—Diagram of primary gas washer.

washer, the Feld gas washer, the Fowler and Medley vertical gas washer, the Schwartz-Bayer disintegrator gas washer, the Theisen disintegrator gas washer, and the ordinary Theisen gas washer. In spite of the fact that the Theisen washer is no more efficient than some others, and costs more to install and more to operate, it is the one mainly used in this country. A brief

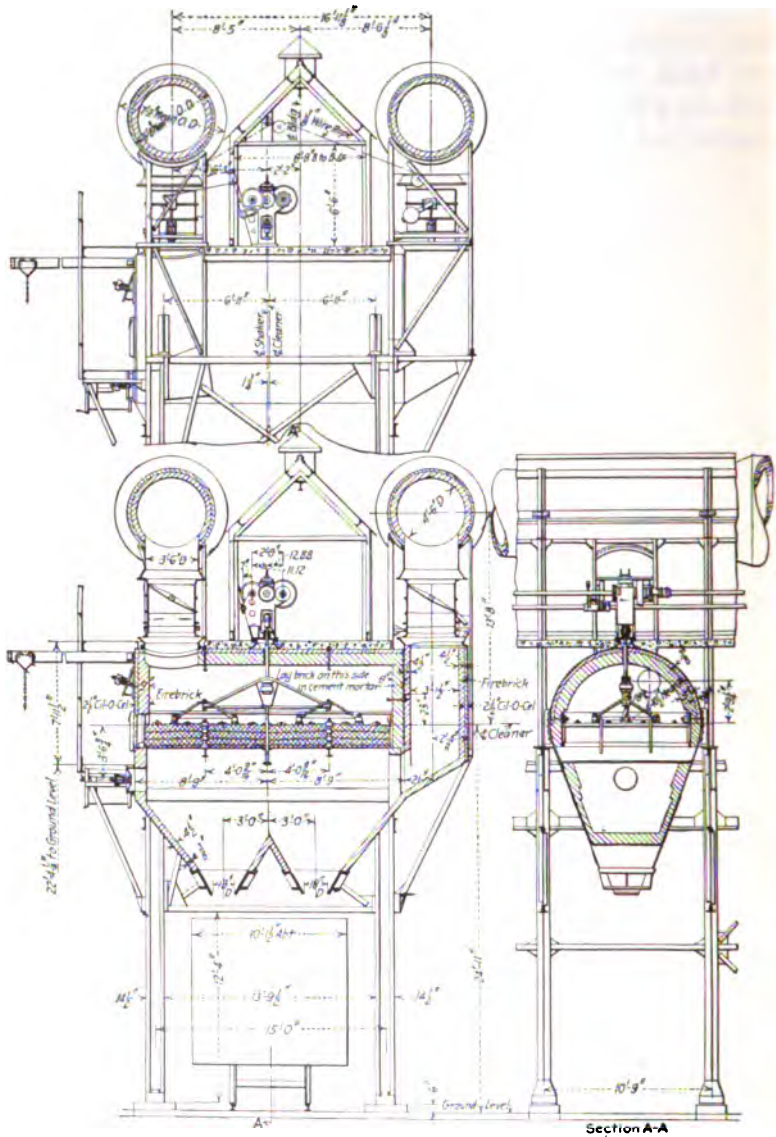


FIG. 317.—Kling-Weidlein dry gas cleaner. General arrangement of sections of one of the compartments, showing a filter of the single mat type. The course of the gas through the filter is indicated by the arrows.

description of this washer is, therefore, given to illustrate the general principles involved in this method of final cleaning.

The Theisen cleaner is a combination fan and cleaner. It consists of an outer stationary steel casing lined with a special wire netting, within which there revolves, at high speed, a drum carrying a number of vanes or blades each set so as to form a spiral curve. At the receiving end the vanes project beyond the end of the cylinder to form a drawing fan for receiving the gas, while at the delivery end they terminate in blades, attached to the same cylinder, that act as a booster fan for propelling the gas through the succeeding apparatus. Water is admitted at low pressure through six pipes half-way up and on the side of the outer shell. This water is dashed to a spray by the revolving vanes, and, being propelled in a direction opposite to that of the gas, is thoroughly mixed with it, thus wetting the last small particles of dust, which must, therefore, separate with the water. This water is let out of the apparatus through a water seal at the bottom. The gas flows through the shell and out into a water separator, thence to the gas main leading to the gas engines. Usually these cleaners have a rated capacity of about 14,000 cu. ft. of gas per minute at standard conditions, and approximately 45 cu. ft. of gas are cleaned per gallon of water used.

CHAPTER XVII

THE DAYTON PROCESS

By

F. C. Binnall*

The Dayton process of gas manufacture is essentially an air-oil gas process, in which partial combustion of certain constituents of the oil takes place within the retort or reaction chamber itself, thus supplying internally all the heat necessary for the thermal decomposition of the hydrocarbons. Thermodynamically internal combustion gives the highest heat efficiency in furnishing the requisite energy for oil gas production. Over 88 per cent of the heat in the oil is obtained in a useable form as gas or tar. *The fact that no external heating is required distinguishes it from other methods of artificial gas making.*

The only raw material necessary is a liquid hydrocarbon, such as gas oil or fuel oil, which is atomized and mixed with preheated air in predetermined and automatically maintained proportions, and fed continuously into suitable retorts or reaction chambers located within properly insulated settings. Within the retorts partial combustion of the carbon and hydrogen takes place with the oxygen of the air, generating sufficient heat continuously to maintain the reaction temperature, to take care of heat lost through radiation and conduction, and the sensible heat carried out in the hot gases. This partial combustion is sufficient to carry as carbon monoxide or carbon dioxide that portion of carbon which otherwise would be deposited as lampblack. By this method of production there is delivered as a combustible practically all the carbon of the oil, the loss of which in ordinary destructive distillation and carbureting processes produces a lowering of efficiency. As the lampblack carbon is burned within the retort, there is no clogging and thus no troublesome shut downs.

* Chemical Engineer, 162 N. Grove St., East Orange, N. J.

The Dayton process provides a substantial and simple apparatus for the manufacture of gas which is easily controllable within the heat unit range of commercial uses. The gas-make is continuous, uniform, and automatic except for nominal control, irrespective of the gas make per unit of time. The oil and air settings on the atomizer are made initially for the particular grade of gas desired, and, when once adjusted, the ratio of air to oil cannot vary. Thus the maintenance of this fixed ratio insures a continuous production of the grade of gas desired. If the ratio of air to oil is varied, the temperature of the retort and the quality of the gas will vary; for if more air is added, the partial combustion of the hydrocarbons will be more complete, thus generating more heat per unit of time, resulting in higher temperatures in the retort. The higher temperatures bring about a change in the quality of the gas. On this basis, it is obvious that the production of a very lean gas will bring about prohibitive retort temperatures. Contra-wise, the upper limit of gas B.t.u. possible is represented by that ratio of air to oil which will bring about sufficient incomplete combustion for maintenance of proper temperatures. And within these limits, which approximate a 300 to 560 B.t.u. gas, any grade of gas can be produced continuously and varied at will.

Above 560 B.t.u. per cubic foot external heating is necessary, as the air supplied for this heat content does not permit of enough partial combustion to liberate sufficient heat to sustain the reaction. The lower limit of B.t.u. possible is approximately 300 B.t.u. per cubic foot. The production of a gas with a lower heating value than this causes undesirably high retort temperatures and inefficient operating conditions.

The production of 450 to 500 B.t.u. gas produces a maximum efficiency thermally and allows the maximum production per unit of time. Also conditions which bring about the production of such a gas, afford by-products in suitable quantity and quality.

The air supplied for the partial combustion during the gas-make stage is preheated by the exit hot gases leaving the retort. This preheated air is mixed intimately with the oil at the atomizer, and is supplied together with the oil through a pipe into the center of the retort. Thus complete vaporization of oil and admixture with the air are insured before entering the hot zone, and there is no decomposition of the oil in the liquid phase to

augment carbon deposition. By this method of prevaporization, the maximum surface of the oil molecules is exposed to the heat of the reaction chamber, insuring an efficient gas-make state. A vacuum is known to promote the formation of unsaturated hydrocarbons in the gaseous phase. In the Dayton process the large percentage of inert nitrogen present in the air supplied for partial combustion brings about a lowering of the partial pressure on the hydrocarbons in the gaseous state, acting as though an actual vacuum had been applied on the hydrocarbon system. Thus, in the "cracking" or gas-make stage, the conditions are proper for the formation of the maximum production of unsaturated compounds which possess a high heating value. It follows, then, that, due to the production of these unsaturated compounds, the process is capable of producing a *high heating value gas with a high nitrogen content.*

Since in the process the surface and pressure (approximately atmospheric) on the gas-make system are constant, and the concentration, time and temperature are under control for any predetermined condition, it follows that, when once started, the process will *deliver continuously and automatically the grade of gas desired.*

The gas produced is relatively free from sulphur compounds and mechanical impurities such as dust particles, and no purification is necessary for the production of a clean gas. The fact that the sulphur in the oil is oxidized to its dioxide during the gas-make stage brings about a practically sulphur-free gas, as the sulphur dioxide passes out with the waste water from the hydraulic main and water scrubber. The practical effect of this result is such that, in commercial installations, in producing 100 cu. ft. of gas from a quantity of oil carrying 310 grains of sulphur, there are present in the unpurified gas only 8.3 grains of the total sulphur. Since, under most statutes, purified illuminating gas is permitted to carry 30 grains or more of sulphur per 100 cu. ft., it obviously follows that, when using any of the commercially obtainable oils, no purification for sulphur will be required.

No large gas holder is necessary with the Dayton process, as with other systems where the gas-make is intermittent, or where there are wide variations in the quality of the gas requiring an "averaging up." Only a small regulator gasometer of about 300 cu. ft. capacity is required. If there is a sudden

decrease in consumption, or the demand for gas is curtailed, the apparatus instantly adjusts the gas-make to this condition by reducing the air pressure on the air and oil feed system to a point where the gas-make equals the demand. The make correspondingly is increased automatically when the demand increases. During these automatic changes in rate of gas-make, the B.t.u. of the gas will not vary, due to the maintenance of the constant ratio of air to oil at the atomizer under all conditions.

The apparatus is started by heating the retorts externally to the reaction temperature. Less than 1 hr. is required to bring a cold retort to operating efficiency. Where the load factor is such that a portion of the plant is in operation over the full 24 hrs. of the day, the entire plant is always ready to deliver its maximum output instantaneously, for the reaction temperatures are maintained constantly in the balance of the settings. However, where the plant is shut down entirely over night or Sunday, the settings are so insulated that the burner provided need be operated less than three-quarters of an hour to obtain the necessary retort temperatures for gas-making. In case consumption is curtailed for 2 or 3 hrs., the heats in the retorts are maintained by the insulation, and gas-making can be started instantaneously without the application of external heat.

The complete installation is small and compact. Only 1,500 sq. ft. of floor space is required for a plant with a production of 1,000,000 cu. ft. per day. In addition, there is required no auxiliary steam generating or purifying equipment, thus making the process simple and self-contained.

The labor required is small. One man per shift is sufficient to operate a plant of 1,000,000 cu. ft. capacity per day. His duties are only nominal and supervisory; for, when once started, the process is continuous and automatic. His main responsibility is to see that the oil supply tanks are filled, and that the compressor is lubricated properly. There are no raw materials to be conveyed or handled, as in an ordinary gas plant.

Approximately 4.00 gal. of fuel or gas oil is required for the production of 1,000 cu. ft. of 450 B.t.u. gas. From this amount there is recovered 0.28 gal. of tar. As the tar may be equal in value (see data below) to an equivalent quantity of the oil used, for comparison purposes, then $4.00 - 0.28 = 3.72$ gal. of oil actually is consumed per 1,000 cu. ft. of 450 B.t.u. gas.

Heat Balance for Production of 450 B.t.u. Dayton Gas

Oil used		4.00 gal.
Tar recovered		0.28 gal.
Oil consumed		3.72 gal.
Heat supplied:		
4 gal. oil @ 136,000 B.t.u. per gal		544,000 B.t.u.
Heat recovered:		
1,000 cu. ft. gas @ 450 B.t.u. per cubic foot	450,000 B.t.u.	
0.28 gal. tar @ 136,000 B.t.u. gal	38,080 B.t.u.	
Total heat recovered		488,080 B.t.u.
Heat loss		55,920 B.t.u.

$$\text{Heat in gas} = \frac{450{,}000}{544{,}000} = \ldots\ldots \quad 82.72 \text{ per cent}$$

$$\text{Heat in tar} = \frac{38{,}080}{544{,}000} = \ldots\ldots \quad 7.00 \text{ per cent}$$

$$\text{Heat lost} = \frac{59{,}920}{544{,}000} = \ldots\ldots \quad 10.28 \text{ per cent}$$

Total 100.00 per cent

Physical Characteristics of 450 B.t.u. Dayton Gas

Specific gravity 1.02

Chemical Characteristics of 450 B.t.u. Dayton Gas

	Per Cent By Volume
CO_2	6.1
Unsaturated hydrocarbons	14.7
O_2	0.9
CO	5.6
Saturated hydrocarbons	7.8
H_2	1.7
N_2	63.2
Total sulphur	3 to 8 grains per 100 cu. ft.
Flame temperature (theoretical)	3,700°F.

Comparison of Nitrogen Content in Mixtures of 100 Cu. Ft. of 450 B.t.u. Dayton Gas and 630 B.t.u. City Gas with Air, Ready to Burn

Air required per cubic foot of Dayton gas 3.60 vol.
Air required per cubic foot of city gas 5.58 vol.

	Dayton Gas 450 B.t.u.	Illuminating Gas 630 B.t.u.
Nitrogen in 100 cu. ft. of gas	63.2	6.8
Nitrogen from air	292.2 (3.60 vol.)	442.0 (5.58 vol.)
Nitrogen in mixture	355.4 cu. ft.	448.8 cu. ft.

COMBUSTION DATA

	DAYTON GAS 450 B.T.U.	ILLUMINATING GAS 630 B.T.U.
B.t.u. per cubic foot of combustible mixture	97.50	95.8
Convection efficiency	49.75 per cent	46.3 per cent

Theoretically it has been found, and under practical conditions of industrial operation it has been proved, that Dayton gas of 450 B.t.u. per cubic foot is required in *no greater volume* than illuminating gas of 630 B.t.u. per cubic foot for the same work.

This is due to the *higher flame temperature;* to the *smaller weight of combustion products* per cubic foot of gas burned, thus *less heat lost in the waste gases;* and to the *smaller differences* between the high and low heating values of the gas, as evidenced by the difference in the weight of water formed during the combustion of the two gases.

From each 1,000 cu. ft. of 450 B.t.u. gas produced, there is recovered 0.28 gal. of tar, the characteristics of which are given in Table CIX below. By compression to only 30 lb. per square inch and cooling to 32°F., it is also possible to recover 0.35 gal. of light oil which distils completely below 170°C. (see Table CX below). The removal of this light oil produces a lowering of the B.t.u. *in the gas of less than 4 per cent.*

TABLE CIX.—DAYTON GAS TAR: DISTILLATION TEST

	A	B
Specific gravity	0.986	0.988
First drop, degrees Centigrade	85.0	83.0
Fraction up to 80°C.	None	None
Fraction 80–170°C., per cent	13.8	10.2
Fraction 170–230°C., per cent	26.8	26.8
Fraction 230–270°C., per cent	15.2	18.4
Fraction 270–360°C., per cent	31.6	32.0
Pitch, per cent	11.3	12.7
Water, per cent	0.6	0.6
Loss, per cent	0.7	0.7

TABLE CX.—DAYTON GAS LIGHT OIL: DISTILLATION TEST

	C	D
First drop, degrees Centigrade	35.0	35.0
Water, per cent	None	0.2
Light naphtha up to 80°C., per cent	14.0	9.8
Crude benzol 80–100°C., per cent	37.2	54.4
Crude toluol 100–120°C., per cent	20.0	16.4
Crude xylol 120–145°C., per cent	14.0	8.8
Solvent naphtha 145–170°C., per cent	9.6	9.0
Residue above 170°C., per cent	4.4	1.4
Distillation loss, per cent	0.8	1.4

The various fractions of light oil, purified by treatment with sulphuric acid and caustic soda, gave on redistillation.

TABLE CXI

	C	D
Light naphtha up to 80°C., per cent.	14.0	9.8
Purified benzol 80–100°C., per cent.	26.0	43.7
Purified toluol 100–120°C., per cent.	12.7	15.8
Purified xylol 120–145°C., per cent.	12.7	1.6
Solvent naphtha 145–170°C., per cent.	8.8	7.5
Residue above 170°C., per cent.	4.4	1.4
Removed by sulphuric acid, per cent.	21.4	20.2
Paraffins in fractions 80–145°C.	None	None

It is interesting to note that the total yield of aromatic compounds of the benzene series is greater than the yield obtained by so-called high temperature and high-pressure pyrolytic ("cracking") processes. In addition, these compounds are produced free from saturated aliphatic compounds, thus making their purification.

COST PER THOUSAND CUBIC FEET OF DAYTON GAS

Based on results obtained commercially, the cost production of 1,000 cu. ft. of 450 B.t.u. gas, in a plant producing 1,000,000 cu. ft. of gas daily, with the labor of one man per shift, becomes as follows:

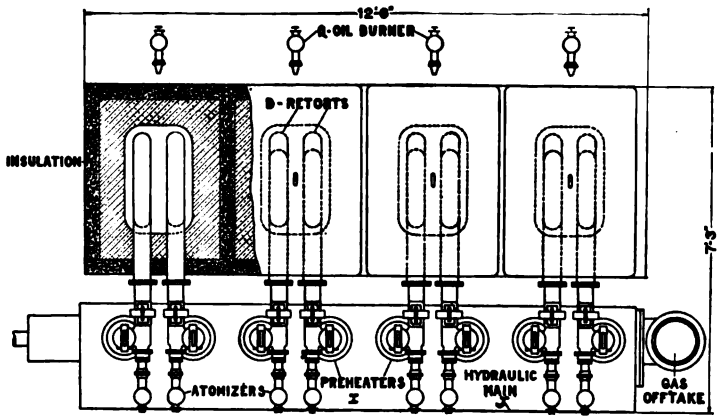
COST OF PRODUCTION 450 B.T.U. DAYTON GAS

	CENTS
Oil, 4.0 gal. @ 6 cts. per gallon	24.00
Power, $\frac{3}{5}$ kw.-hr. per thousand of gas @ 1.5 cts. per kilowatt-hour	0.90
Water, 8 cu. ft. @ 30 cts. per thousand cubic feet	0.24
Labor, 1 man per shift at 55 cts. per hour	1.32
Plant maintenance @ 3 cts. per thousand of gas	3.00
Total gross cost	29.46
Credit 0.28 gal. tar @ 6 cts. per gallon	1.68
Net cost per thousand cubic feet	27.78

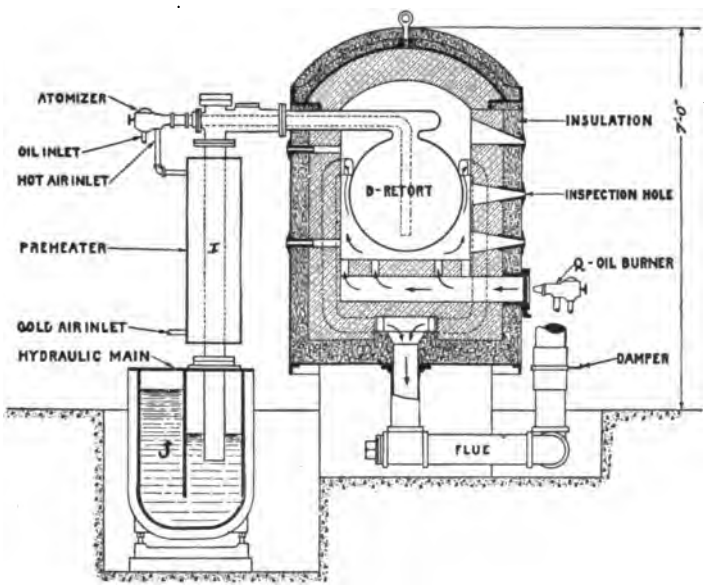
No account is taken of the light oils obtainable as by-products.

DESCRIPTION OF DAYTON APPARATUS

Figure 318 gives the complete diagrammatic elevation of the Dayton oil gas apparatus. A single motor, *A*, is the sole motive power for the air, *B*, and oil, *C*, fed to the generator, *D*,



TYPICAL PLAN OF GENERATING UNIT OF EIGHT RETORTS
CAPACITY 600,000 CU.FT. PER DAY



SECTION THROUGH STANDARD GAS GENERATOR UNIT

FIG. 318.—Dayton oil-gas apparatus.

and for the exhauster, *E*, on the finished gas system. Thus, as all units are synchronous, all factors are maintained in their predetermined ratios. The air-feed system is connected directly to the service oil tank, *F*, and to an air-regulating valve, *G*, on the gasometer, *H*. Thus, if the gas-make is greater than the gas consumption, the gasometer will rise, release the air regulator valve, and decrease the air pressure on the air-feed line and on

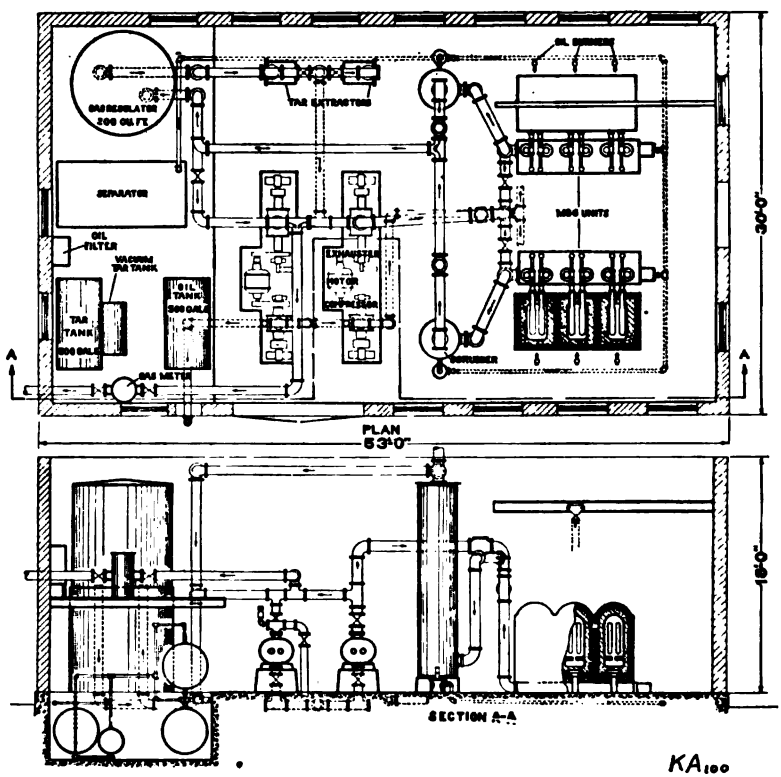


FIG. 319.—Layout of a Dayton oil-gas plant having a capacity of one million cubic feet per day.

the oil-service tank. As the pressure on the air and oil supply have decreased the same amount, the ratio of feed at the retort has decreased substantially in the same ratio. And *vice versa*, should the consumption be greater than the make, the gasometer falls, the air-regulating valve closes, and the air pressure on the air and oil systems increases, thus increasing the oil and air entering the retort in the same constant ratio, increasing the gas-make.

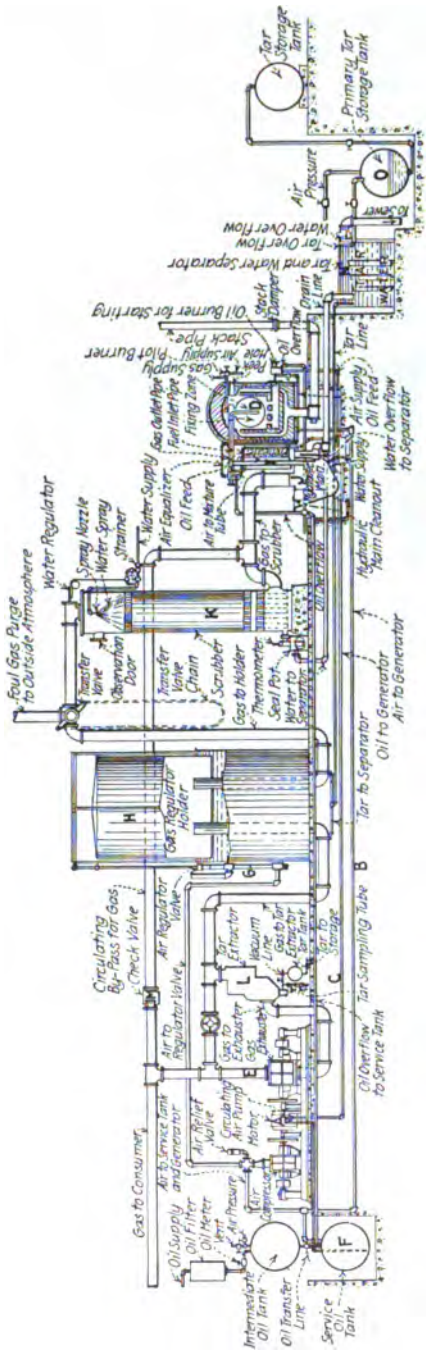


FIG. 320.—Typical layout diagram of Dayton gas plant.

As the ratio of oil to air cannot vary, the temperature of the retort cannot vary, and consequently the B.t.u. content of the gas cannot vary. *This constant ratio air-oil feed is the basic controlling principle of the successful operation of the Dayton oil-gas process.* As can be seen, it is automatic in operation for any grade of gas desired and for any make per unit of time.

The hot gases and vapors from the retort pass through a heat interchanger, *I*, giving up a portion of their heat content to the incoming air, thence into the hydraulic main, *J*, where they are initially cooled and part of the vapors removed. From there

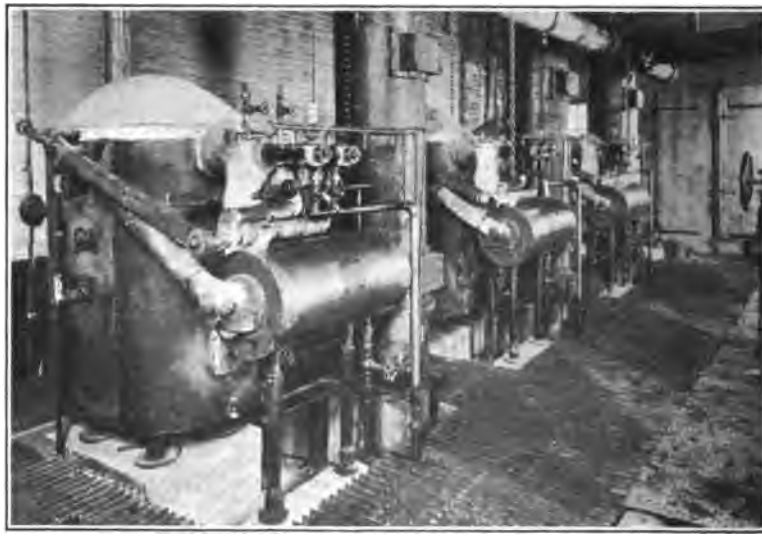


FIG. 321.—General view of a 450,000 cu. ft. per day plant installed at the Aluminum Castings Company, Cleveland, Ohio. Photo taken from the "left."

they pass to the water scrubber, *K*, where they are further cooled, and more vapors removed, and then directly to the regulating holder. From the regulating holder, they pass through a tar extractor, *L*, to an exhauster which supplies the gas main. In case the gas is delivered from the exhauster in greater quantities than are consumed, it is returned to the hot gas line and enters the scrubber through a check value, *M*, thus building up the gasometer which automatically operates the air-regulating valve on the air supply to the system.

The water from the scrubber and hydraulic main is removed by way of the separator, *N*, where the tar separates and passes

into the primary storage, *O*, and the water passes to the sewer through the overflow.

The tar from the tar extractor, *L*, is recovered in the primary tar tank, *P*, and then is transferred to the tar storage tanks.

Figure 318 shows a cross-section of the retort or generator with the details of the necessary auxiliaries, together with the

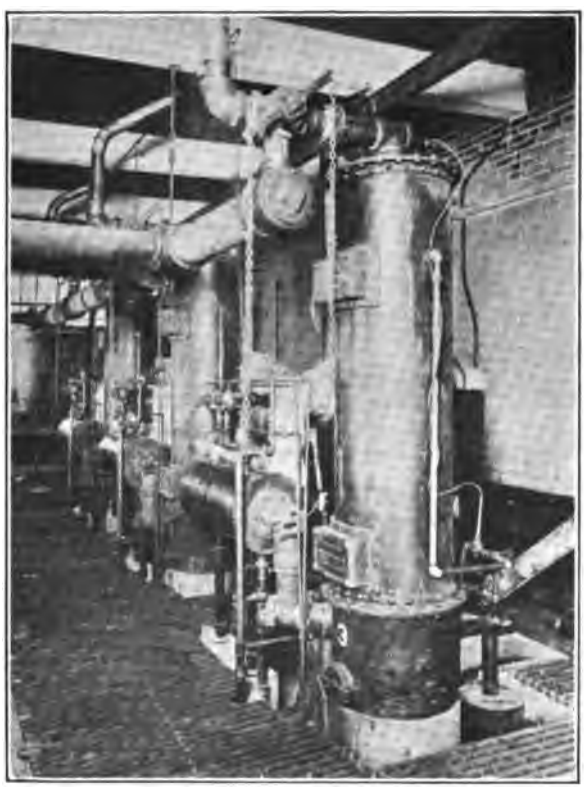


FIG. 322.—General view of a 450,000 cu. ft. per day plant installed at the Aluminum Castings Company, Cleveland, Ohio. Photo taken from the "right."

burner, *Q*, which is used in heating the retort up to the reaction temperature in starting.

The retort, or reaction chamber, operates under low pressures, never exceeding 2 lb. per square inch gage pressure at a maximum. It is a section of a sphere and is approximately 24 in. in diameter; it forms a chamber which internally is 4 in. in breadth. The actual volume barely exceeds 0.5 cu. ft. for a retort with a daily output of 80,000 cu. ft. of gas. The retorts

are assembled in units of two and multiples of the same up to any desired number needed. The construction is such that any one

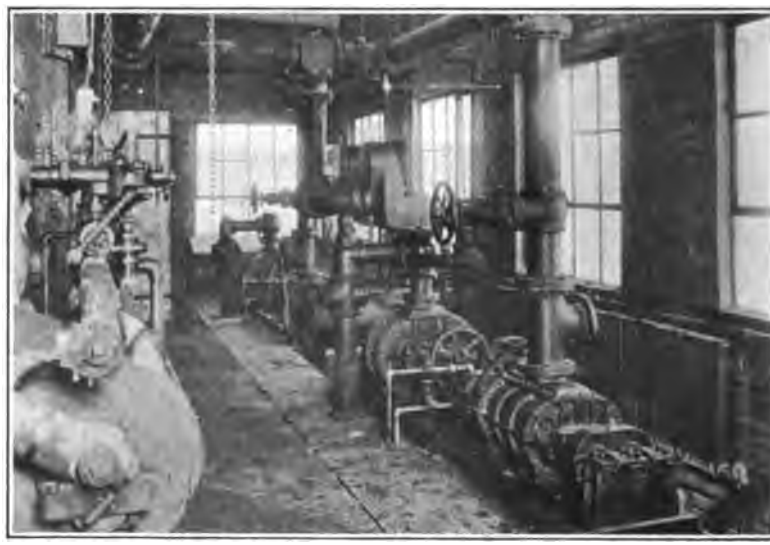


FIG. 323.—Compressor, exhauster, and tar extractor equipment installed at the Aluminum Castings Company, Cleveland, Ohio.

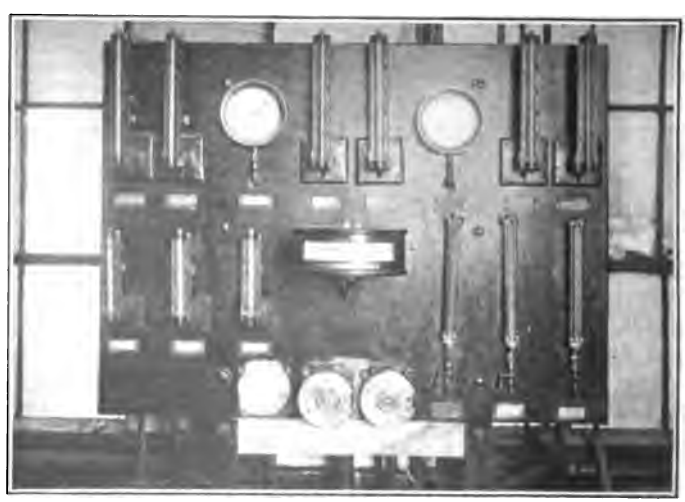


FIG. 324.—Gage board, installed at the Aluminum Castings Company's plant, Cleveland, Ohio.

or more of the retorts may be cut out without interfering with, or affecting, the remainder of the set. Thus the failure of a

single unit will not interrupt gas making or seriously curtail the output of any commercial size installation. The retorts can be changed by two men within an hour. The life of a retort compares well with the life of an ordinary water gas generator.

Figure 319 shows a plan view of a multiple generator set of eight retorts, together with the atomizers, air preheaters and hydraulic main.

Figure 320 shows a typical layout of a Dayton gas plant of 1,000,000 cu. ft. capacity per day. It presents the plant complete with all the necessary auxiliaries all housed in a building 30 ft. by 53 ft. with 18 ft. of headroom.

Figure 321 shows a front view of three units installed in a large industrial plant. This installation produces 500,000 cu. ft. of gas a day.

Figure 322 shows another view of this same installation.

Figure 323 shows a dual installation of motors, blowers and exhausters at this plant.

Figure 324 gives a view of a typical control board on a Dayton plant. Here all the control factors are directly under the operator's view at all times.

CHAPTER XVIII

THE RELATIVE VALUES OF GASEOUS FUELS

By

F. C. Binnall*

In making a comparison of combustibles, it is necessary to have a knowledge of the variation in specific heats of the gaseous products of combustion. Due to the fact that little is known on this important subject almost every combustion engineer bases his calculations upon a different authority. And for as many authorities cited, there are as many different solutions.

The determinations of specific heats of gases that are probably the most valuable are those of Langen and LeChatelier. Langen did not correct for radiation in his experiments, and they are, therefore, open to some criticism. His results agree quite closely with LeChatelier's at low temperatures, but above 3,000°F., there is quite a large variation. Due to this fact, LeChatelier's constants when used agree more closely to the results obtained in practice.

Formulas for the Determination of Thermal Capacities at Constant Pressure of Gases in B.t.u. per Pound at Any Degree Fahrenheit

(Based on LeChatelier's Specific Heat Determinations—Dissociation Neglected)

Air	Q† =	$11.41 \times 10^{-6t^2}$	+	$0.235t$	−	7.543
Oxygen	Q =	$10.56 \times 10^{-6t^2}$	+	$0.212t$	−	6.810
Nitrogen and carbon monoxide	Q =	$11.67 \times 10^{-6t^2}$	+	$0.242t$	−	7.764
Carbon dioxide	Q =	$46.67 \times 10^{-6t^2}$	+	$0.19t$	−	6.128
Water vapor	Q =	$90.0 \times 10^{-6t^2}$	+	$0.441t$	−	14.210
Hydrogen	Q =	$166.6 \times 10^{-6t^2}$	+	$3.389t$	−	108.630
Methane	Q =	$207.8 \times 10^{-6t^2}$	+	$0.5948t$	−	19.244

LeChatelier's work was all done in gram calories and degrees Centigrade, and is very hard to interpret when working in B.t.u. per pound and degrees Fahrenheit. To facilitate the work when dealing with combustion problems, the following formulas have been derived to express the Thermal Capacities of Gases in B.t.u. per pound at any degree Fahrenheit.

* Chemical Engineer, 162 N. Grove St., East Orange, N. J.

† Calculated from air and nitrogen formulas.

They are derived from results that LeChatelier obtained for the gases in gram calories and degree Centigrade.

From the above formulas, the following thermal capacities of gases have been calculated. The results agree within + 3 B.t.u. per pound of LeChatelier's original work transposed.

THERMAL CAPACITIES OF GASES UNDER CONSTANT PRESSURE IN B.T.U. PER POUND AT DEGREES FAHRENHEIT

Degrees Fahrenheit	Air	Oxygen (O_2)	Nitrogen and carbon monoxide (N_2 and CO)	Carbon dioxide (CO_2)	Water vapor (H_2O)	Hydrogen (H_2)	Methane (CH_4)
200	40.12	36.01	41.11	33.73	77.60	577.63	108.03
400	88.29	79.68	90.90	77.33	176.60	1,278.22	251.93
600	137.56	124.19	141.65	124.67	282.80	1,980.14	412.45
800	187.76	169.54	193.30	175.73	396.20	2,716.39	589.59
1,000	238.87	215.75	245.91	230.54	516.80	3,456.00	783.36
1,200	290.89	262.92	299.44	289.07	644.60	4,208.87	993.75
1,400	343.82	310.69	353.91	351.34	779.60	4,975.10	1,220.77
1,600	397.67	359.42	409.31	419.34	921.80	5,754.66	1,464.41
1,800	452.43	409.00	465.65	487.08	1,071.20	6,547.55	1,724.67
2,000	508.10	459.43	522.92	560.55	1,227.80	7,353.80	2,001.56
2,200	564.70	510.70	581.12	637.75	1,391.60	8,173.31	2,295.07
2,400	622.18	562.82	640.25	718.69	1,562.60	9,006.18	2,605.21
2,600	680.59	615.78	700.32	803.36	1,740.80	9,852.38	2,931.97
2,800	739.91	669.58	761.33	891.76	1,926.20	10,711.91	3,275.35
3,000	800.15	724.23	823.24	984.87	2,118.80	11,584.77	3,635.36
3,200	861.30	779.72	886.14	1,079.77	2,318.60	12,470.95	4,011.99
3,400	923.36	836.06	950.44	1,179.37	2,525.60	13,370.47	4,405.25
3,600	986.33	893.25	1,014.68	1,282.71	2,739.80	14,283.31	4,815.13
3,800	1,050.27	951.32	1,080.40	1,389.97	2,961.56	15,210.14	5,242.46
4,000	1,115.02	1,010.15	1,146.96	1,500.59	3,189.80	16,148.97	5,684.76
4,200	1,180.73	1,069.87	1,214.50	1,615.13	3,426.20	17,101.79	6,144.51
4,400	1,249.36	1,130.43	1,282.97	1,733.40	3,668.60	18,067.95	6,620.88
4,600	1,314.90	1,191.84	1,352.37	1,855.41	3,918.80	19,047.43	7,113.89
4,800	1,383.35	1,254.09	1,422.71	1,981.15	4,176.20	20,040.23	7,623.51
5,000	1,452.71	1,317.19	1,493.99	2,110.62	4,440.80	21,046.37	8,149.76

This table is plotted for all temperatures up to 4,200°F. in Fig. 325.

In making a comparison of the various industrial gases, the above data on the thermal capacities of gases have been used throughout all calculations.

For comparing the value of different gases, there have been chosen:

1. A natural gas
2. A coal gas
3. 500 B.t.u. Dayton gas
4. 457 B.t.u. Dayton gas

5. 394 B.t.u. Dayton gas
6. A blue water gas
7. A producer gas

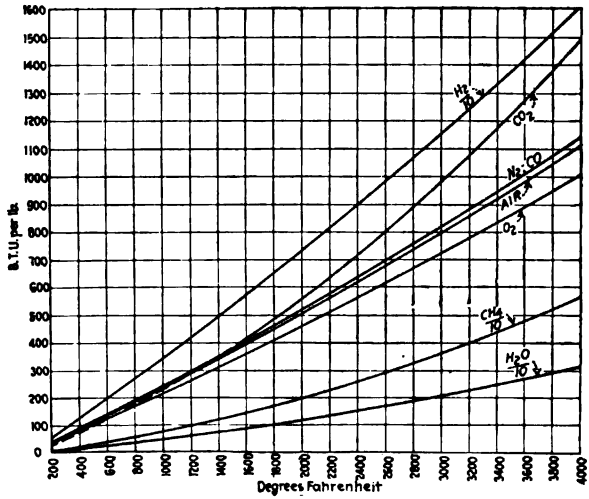


FIG. 325.—Thermal capacity of gases, expressed in B.t.u. per pound in degrees Fahrenheit, based on LeChatelier's specific heat determinations (dissociation neglected). Formulas derived and calculated by the General Oil Gas Corporation.

The high and low heating values in B.t.u. per cubic foot of these gases are as follows:

Gas	Natural	Coal	Dayton	Dayton	Dayton	Water	Producer
High heating value	970	630	500	457	394	301	135
Low heating value	883	550	474	433	372	278	127

The analyses by volume of the gases chosen for comparison are:

B.t.u., cubic feet of gas	970 Natural	603 Coal	500 Dayton	457 Dayton	394 Dayton	301 Water	135 Producer
Constituents:							
CO_2, per cent	0.0	1.5	6.0	6.1	5.1	6.0	5.2
Unsaturated hydrocarbons	0.0	4.0	15.9	14.7	11.1	0.0	0.0
O_2	0.0	0.5	0.1	0.9	0.8	0.5	0.4
CO	2.0	6.0	6.7	5.6	9.8	38.0	22.9
H_2	0.0	50.0	2.3	1.7	4.5	48.0	15.3
Saturated hydrocarbons	96.0	36.0	8.7	7.8	7.6	2.0	1.0
N_2	2.0	2.0	60.3	63.2	61.1	5.5	55.2

From the analyses of the gases, the combustion products were calculated and are given in the table below.

COMBUSTION PRODUCTS IN POUNDS FROM 1 CU. FT. OF GAS

B.t.u. gas	970 Natural	603 Coal	500 Dayton	457 Dayton	394 Dayton	301 Water	315 Producer
Volume air required	9.2300	5.3400	4.0950	3.6940	3.1580	2.2300	0.9900
Pounds CO_2	0.1133	0.0595	0.0799	0.0735	0.0645	0.0532	0.0336
Pounds H_2O	0.0914	0.0610	0.0239	0.0222	0.0199	0.0247	0.0082
Pounds N_2	0.5395	0.3128	0.2837	0.2704	0.2365	0.1342	0.0984
Weights combustion products	0.7442	0.43 2	0.3875	0.3661	0.3209	0.2121	0.1403
B.t.u. per cubic foot combustible mixtures	94.8	95.1	98.3	97.4	94.8	93.2	67.9

The available B.t.u. in a cubic foot of a gas may be expressed as the number of B.t.u. that are available for doing work at the given temperature. In other words, it is the net or low heating value of the gas at 60°F. less the B.t.u. that are consumed in heating the products of combustion to the temperature under consideration. At the temperature where all the B.t.u., as represented by the low heating value of the gas, are consumed in heating up the products of combustion, we have what is called the "reaction" or "flame" temperature. It is the highest tempera-

TABLE CXII.—AVAILABLE B.T.U. OF GASES PER CUBIC FOOT

Degrees Fahrenheit	Gases						
	Natural	Coal	Dayton	Dayton	Dayton	Water	Producer
	Gross B.t.u.						
	970.0	603.0	500.0	457.0	394.0	301.0	135.0
60 Net	883.0	550.0	474.5	433.0	372.0	278 5	127.0
800	722.6	454.5	396.1	359.1	307.0	233.4	98.8
1,200	629.8	399.1	351.0	316.0	269.7	207.0	82.5
1,600	530.3	339.9	302.8	270.0	229.8	178.5	65.1
2,000	425.1	277.1	252.8	223.1	187.7	147.1	46.6
2,400	313.2	210.3	197.3	172.5	143.2	115.7	27.0
2,800	195.4	139.5	140.6	119.0	95.9	81.3	6.3
3,200	70.7	65.2	79.9	62.5	46.5	45.0	
3,400	6.0	26.6	49.6	35.0	20.0	25.9	
3,600			18.1	3 8		6.7	

ture that can be obtained theoretically, assuming that there is no loss by radiation or conduction. Due to the fact that these losses do occur, the temperatures that can be obtained in practice are from 300 to 500°F. lower, depending upon the type of furnace.

From the combustion products of the gases as calculated, and the thermal capacities as expressed in B.t.u., the available B.t.u. per cubic foot of the various gases have been determined for all temperatures. They are given in Table CXII.

From this table the relative value of any gas can be determined. In order to bring out their comparison graphically, the values in Table CXII are plotted in Fig. 326.

It is interesting to note the trend of the very high B.t.u. gases, and the points where the Dayton gas lines cross the lines of available B.t.u. for the higher B.t.u. gases. At the temperatures where they cross, 1 cu. ft. of the lower B.t.u. gases will do the work of 1 cu. ft. of the higher B.t.u. gases.

To express Table CXII by the percentages, the available B.t.u. of the gases at the given temperatures have been divided by the gross B.t.u. per cubic foot. The resultant percentages of B.t.u available are given in Table CXIII.

TABLE CXIII.—PERCENTAGES OF B.T.U. AVAILABLE AT VARIOUS TEMPERATURES

Degrees Fahrenheit	Gases						
	Natural	Coal	Dayton	Dayton	Dayton	Water	Producer
	Gross B.t.u.						
	970.00	603.0	500.00	457.00	394.00	301.00	135.0
60	91.20	91.3	95.00	94.70	94.40	92.50	94.0
800	74.50	75.4	79.30	78.70	77.90	77.60	73.2
1,200	64.90	66.2	70.20	69.10	68.50	68.80	61.1
1,600	54.70	56.4	60.60	59.10	58.30	59.50	48.4
2,000	43.80	45.9	50.50	48.80	47.70	48.90	34.5
2,400	32.20	34.8	39.45	37.70	36.30	38.45	20.0
2,800	20.20	23.1	28.20	26.40	24.30	27.00	4.6
3,200	7.29	10.8	16.00	13.68	11.80	14.95	
3,400		4.4	9.90	7.66	5.08	8.60	
3,600				0.83		2.22	

Often it is desirable to speak of combustibles in terms of million gross B.t.u. instead of cubic feet. Therefore, the percentages of B.t.u. available for all gases have been plotted in Fig. 327, based on one million gross B.t.u. supplied to a given system.

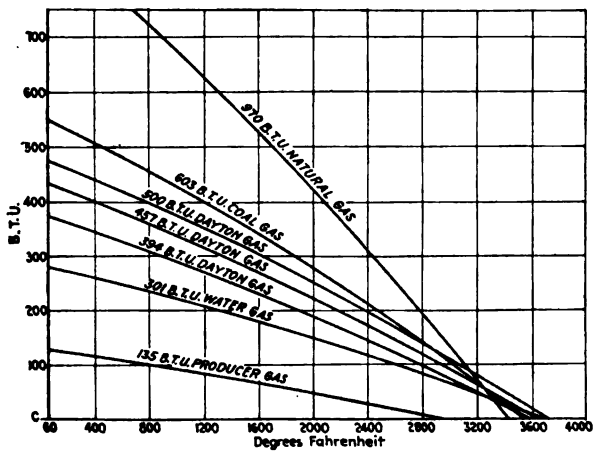


FIG. 326.—Available B.t.u. at various temperatures, based on LeChatelier's thermal capacities.

Owing to the fact that the percentages of available B.t.u. are not the same at any given temperature for all gases, it is incorrect to assume that the value of a gas can be expressed in its equivalent of any other gas based on gross B.t.u. To make a comparison of

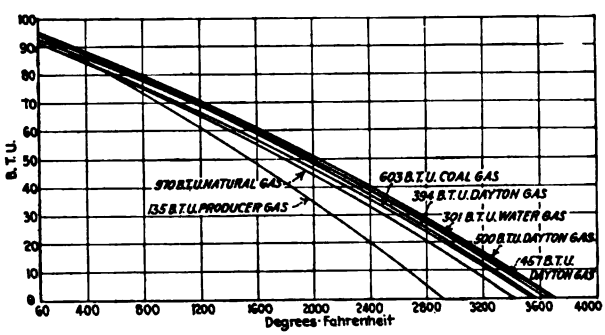


FIG. 327.—Per cent B.t.u. available, based on 1,000,000 B.t.u. supplied.

the cubic feet equivalent, it is necessary to express as a ratio the available B.t.u. of the gases at the given temperature. Such comparisons of the gases given with the three different B.t.u. Dayton gases are to be found in Tables CXIV, CXV and CXVI.

then one gross B.t.u. in a given gas is not equivalent to a gross B.t.u. in another gas. From Tables CXII, CXIV, CXV, and CXVI a B.t.u. in the three different B.t.u. Dayton Gases has been

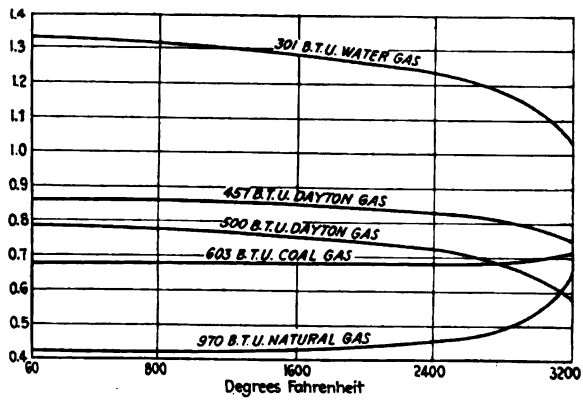


FIG. 330.—Cubic feet of designated gases equivalent to one cubic foot of 394 B.t.u. Dayton gas, based on the B.t.u. available at various temperatures.

determined in its equivalent value of B.t.u. of the other given gases at all temperatures up to 3,200°F. The equivalent values are presented in Tables CXVII, CXVIII and CXIX.

TABLE CXVI.—CUBIC FEET OF DIFFERENT GASES EQUIVALENT TO 1 CU. FT. OF 394 B.T.U. DAYTON GAS

Degrees Fahrenheit	Gases						
	Natural	Coal	Dayton	Dayton	Dayton	Water	Producer
	Gross B.t.u.						
	970.0	603.0	500.0	457.0	394.0	301.0	135.0
60	0.421	0.676	0.784	0.859	1	1.335	2.93
800	0.425	0.676	0.776	0.856	1	1.315	3.11
1,600	0.431	0.676	0.759	0.851	1	1.286	3.53
2,400	0.457	0.681	0.726	0.830	1	1.237	5.30
2,800	0.491	0.688	0.682	0.806	1	1.180	15.22
3,200	0.658	0.713	0.582	0.744	1	1.033	
3,400	3.335	7.520	0.403	0.572	1	0.773	

The equivalent B.t.u. values in Tables CXVII, CXVIII and CXIX, are shown graphically in the respective Figs. 331,332 and 333.

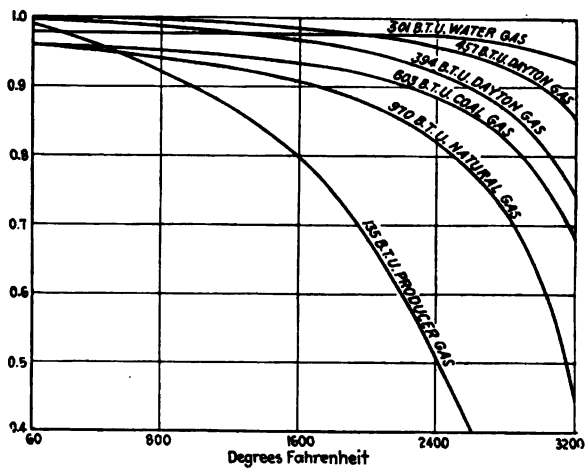


FIG. 331.—B.t.u. of 500 B.t.u. Dayton gas equivalent to one B.t.u. of designated gases at varying temperatures.

TABLE CXVII.—B.T.U. OF 500 B.T.U. DAYTON GAS EQUIVALENT TO 1 B.T.U. OF DESIGNATED GASES AT VARIOUS TEMPERATURES

Degrees Fahrenheit	Gases						
	Natural	Coal	Dayton	Dayton	Dayton	Water	Producer
	Gross B.t.u.						
	970.0	603.0	500.0	457.0	394.0	301.0	135.0
60	0.960	0.960	1	0.999	0.995	0.977	0.990
800	0.941	0.951	1	0.995	0.984	0.977	0.920
1,600	0.905	0.932	1	0.977	0.965	0.977	0.795
2,400	0.819	0.884	1	0.957	0.920	0.974	0.506
2,800	0.716	0.823	1	0.927	0.865	0.960	0.166
3,200	0.456	0.677	1	0.854	0.738	0.933	
3,400	0.062	0.445	1	0.772	0.512	0.867	

In Table CXX and Fig. 334 the cubic feet of the various gases theoretically necessary to heat 100 lb. of iron to the designated temperatures are given. The B.t.u. required to heat 100 lb. of

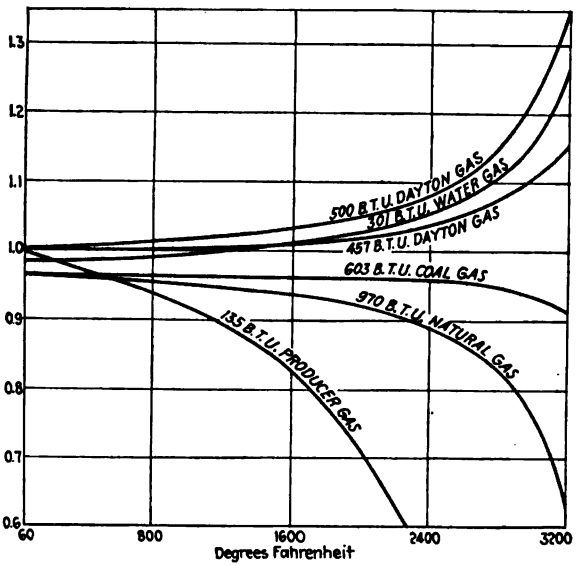


FIG. 332.—B.t.u. of 457 B.t.u. Dayton gas equivalent to one B.t.u. of designated gases at varying temperatures.

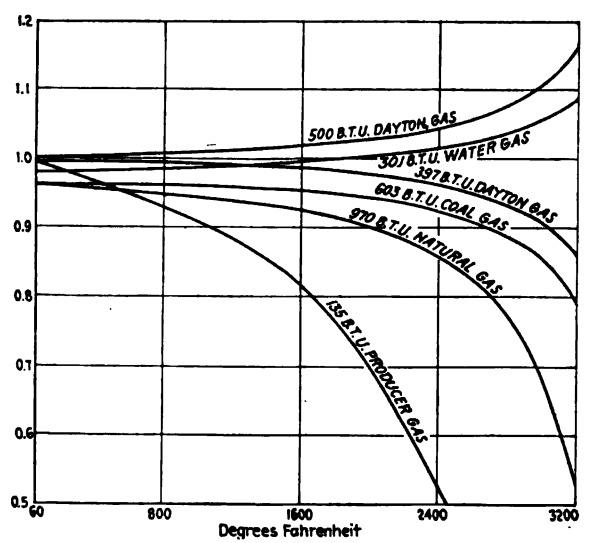


FIG. 333.—B.t.u. of 394 B.t.u. Dayton gas equivalent to one B.t.u. of designated gases at varying temperatures.

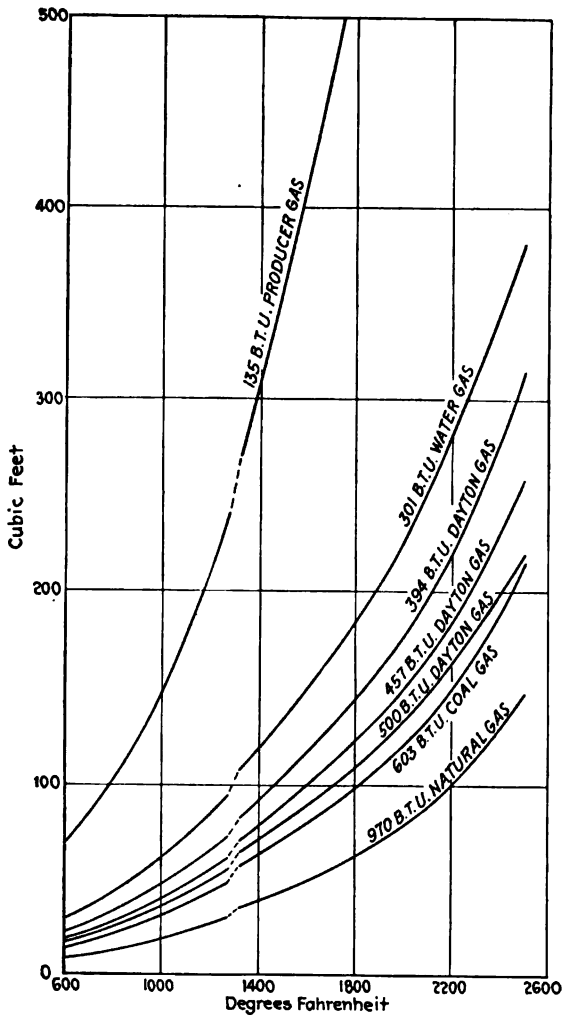


FIG. 334.—Cubic feet of gas theoretically required to heat 100 pounds of iron to the indicated temperatures, based on available B.t.u. calculated from LeChatelier's formulas.

TABLE CXVIII.—B.T.U. OF 457 B.T.U. DAYTON GAS EQUIVALENT TO 1 B.T.U. OF DESIGNATED GASES AT VARIOUS TEMPERATURES

Degrees Fahrenheit	Gases						
	Natural	Coal	Dayton	Dayton	Dayton	Water	Producer
	Gross B.t.u.						
	970.0	603.0	500.0	457.0	394.0	301.0	135.0
60	0.962	0.964	1.002	1	0.997	0.978	0.993
800	0.949	0.960	1.007	1	0.992	0.986	0.930
1,600	0.927	0.954	1.022	1	0.987	0.997	0.816
2,400	0.857	0.924	1.045	1	0.963	1.019	0.530
2,800	0.774	0.889	1.080	1	0.935	1.040	0.179
3,200	0.534	0.790	1.169	1	0.862	1.092	
3,400	0.080	0.576	1.295	1	0.663	1.125	

TABLE CXIX.—B.T.U. OF 394 B.T.U. DAYTON GAS EQUIVALENT TO 1 B.T.U. OF DESIGNATED GASES AT VARIOUS TEMPERATURES

Degrees Fahrenheit	Gases						
	Natural	Coal	Dayton	Dayton	Dayton	Water	Producer
	Gross B.t.u.						
	970.0	603.0	500.0	457.0	394.0	301.0	135.0
60	0.965	0.966	1.005	1.002	1	0.980	0.996
800	0.955	0.966	1.015	1.007	1	0.996	0.938
1,600	0.943	0.966	1.038	1.013	1	1.018	0.826
2,400	0.889	0.959	1.085	1.038	1	1.058	0.550
2,800	0.827	0.949	1.155	1.070	1	1.109	0.192
3,200	0.618	0.916	1.355	1.159	1	1.267	
3,400	0.122	0.868	1.955	1.507	1	1.694	

iron from 32°F. to any designated temperature have been calculated by multiplying the pounds of iron times the mean specific heat from 32° to the designated temperature, then by the temperature itself. The cubic feet of the various gases theoretically necessary to supply this amount of heat were obtained by dividing the heat in B.t.u. required to heat the iron by the available B.t.u. in the designated gas at that temperature.

Even though excess air is not necessary in the utilization of any gas, the question of its effect is often raised. In making a

TABLE CXX.—CUBIC FEET OF GASES THEORETICALLY NECESSARY TO HEAT 100 LB. OF IRON

Degrees Fahrenheit	B.t.u. required	Gases						
		Natural	Coal	Dayton	Dayton	Dayton	Water	Producer
		Gross B.t.u.						
		970.0	603.0	500.0	457.0	394.0	301.0	135.0
600	7,560	9.63	15.75	18.08	19.89	23.20	30.50	70.00
800	10,640	14.65	23.40	26.85	29.60	34.63	45.55	107.70
1,000	13,900	20.58	32.55	37.08	41.10	48.10	62.60	150.40
1,200	17,760	28.21	44.53	50.60	56.20	65.85	85.80	215.20
1,400	23,340	40.50	63.15	71.00	79.20	92.60	120.80	311.30
1,600	27,200	51.32	80.20	89.78	100.70	117.80	152.30	417.80
1,800	30,420	63.70	98.20	109.40	122.70	145.00	185.50	534.00
2,000	33,600	79.05	121.20	133.00	150.60	178.90	228.10	721.00
2,250	37,575	105.75	157.80	172.25	194.60	234.90	298.90	1,074.00
2,500	41,750	147.55	216.20	221.10	261.00	316.20	383.00	1,815.00

comparison of such effect, two gases were chosen, the 457 B.t.u. Dayton gas and a 630 B.t.u. municipal gas. The combustion products and the available B.t.u. of the 630 B.t.u. gas were determined as in the case of the other gases. Ten and twenty per cent excess air then were added to the combustion products and the available B.t.u. determined. The tabulation of the results is given in Table CXXI.

TABLE CXXI.—AVAILABLE B.T.U. WITH VARYING AMOUNTS OF EXCESS AIR

Degrees Fahrenheit	630 B.t.u. gas			457 B.t.u. Dayton gas		
	Excess air, per cent			Excess air, per cent		
	0	10	20	0	10	20
60	572.70			433.0		
800	472.90	464.9	456.9	359.1	353.8	348.5
1,200	415.07	402.6	390.2	316.0	307.6	299.2
1,600	353.30	336.4	319.5	270.0	258.8	247.6
2,000	287.80	226.1	244.4	223.1	208.8	194.5
2,400	217.90	191.3	164.7	172.5	155.0	187.5
2,800	143.90	112.3	80.7	119.0	98.0	77.0
3,200	67.20	30.3		62.5	38.3	14.1
3,400	26.10			35.0	9.0	

The data in Table CXXI are plotted in Fig. 335. At a little above 3,200°F. one cubic foot of 457 B.t.u. Dayton gas is equivalent to 1 cu. ft. of 630 B.t.u. gas. With 10 per cent excess air, a cubic foot of each gas is equivalent at about 3,100°F., and with

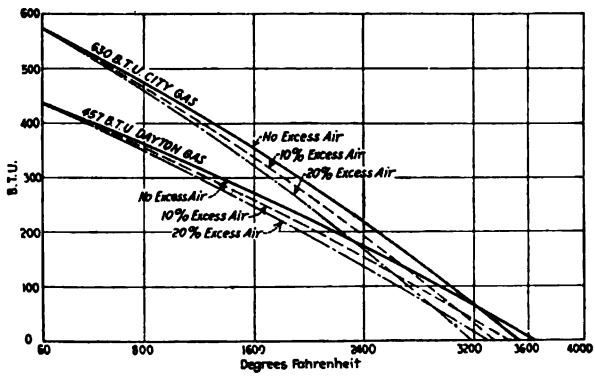


FIG. 335.—Available B.t.u. loss when burning gas with 10 per cent and 20 per cent excess air.

20 per cent excess air, they are equivalent at 2,900°F. This curve also shows the effect of excess air on lowering the "reaction" or "flame" temperature.

Among most engineers, it has been customary to base the

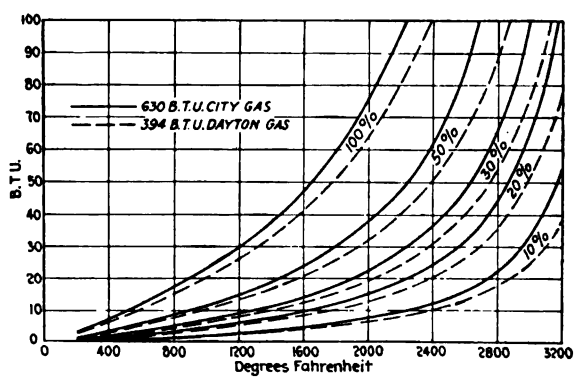


FIG. 336.—Available B.t.u. loss with increasing percentage of excess air at various temperatures.

percentage of heat loss due to excess air on the gross B.t.u. of the gas. However, this procedure is incorrect and leads to erroneous conclusion. The percentage of heat lost due to excess air must be based on the B.t.u. available at the temperature of the waste

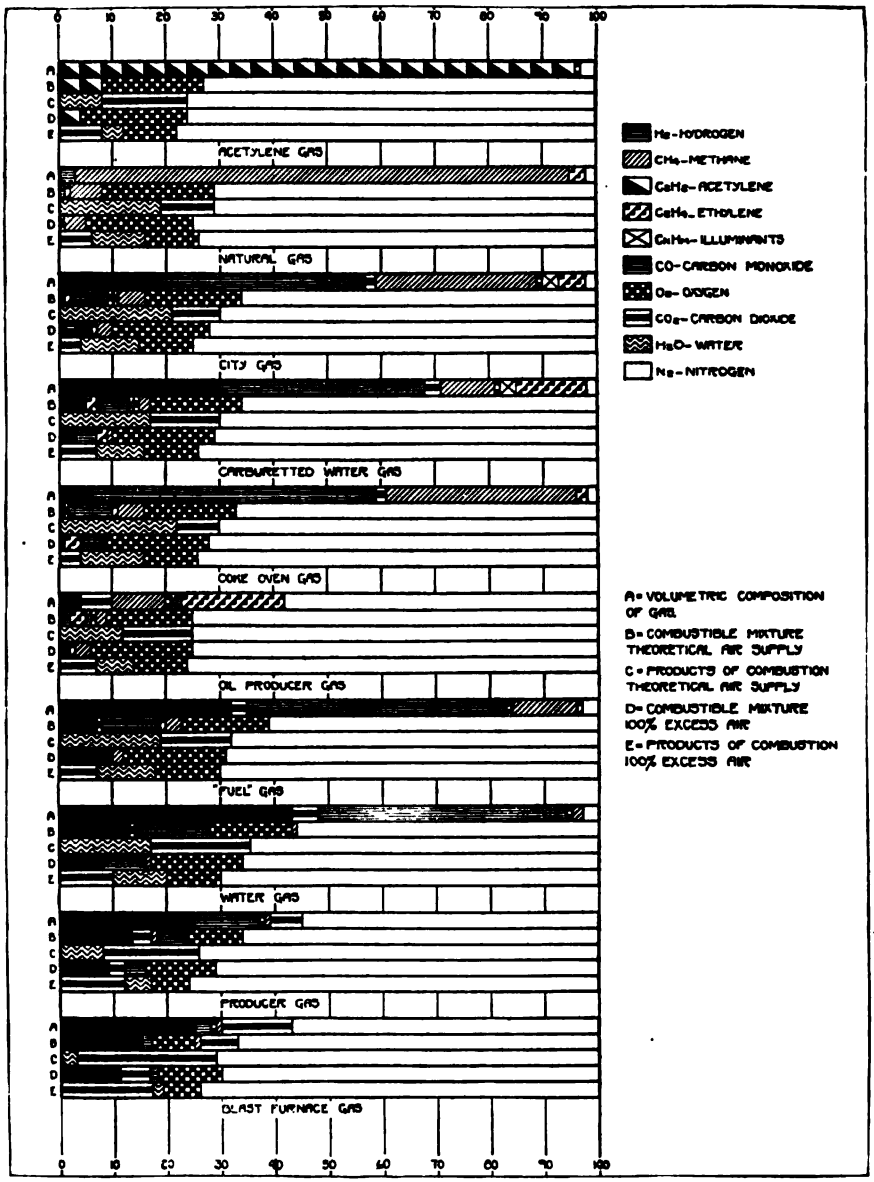


FIG. 337.—Comparison of industrial gases—volumetric composition of gas, combustible mixture and products of combustion. (*Published through the courtesy of the W. S. Rockwell Company, New York.*)

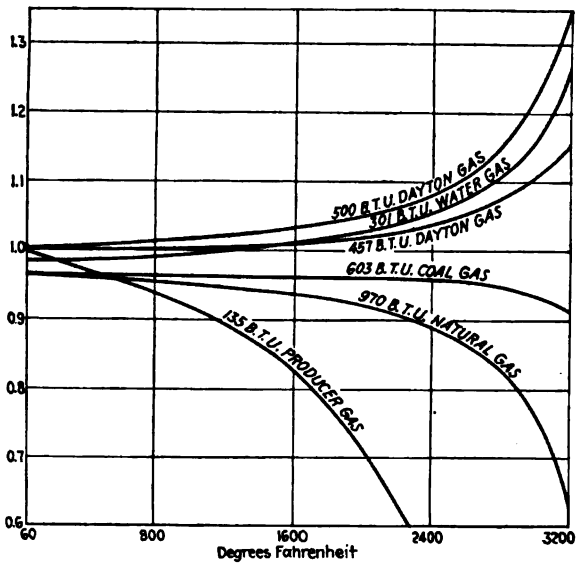


FIG. 332.—B.t.u. of 457 B.t.u. Dayton gas equivalent to one B.t.u. of designated gases at varying temperatures.

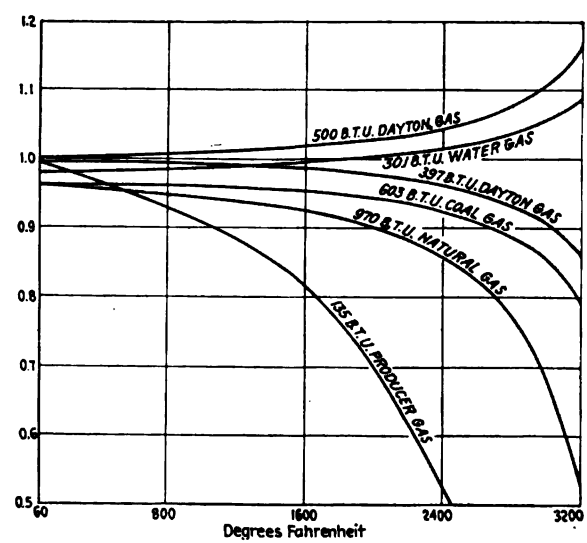


FIG. 333.—B.t.u. of 394 B.t.u. Dayton gas equivalent to one B.t.u. of designated gases at varying temperatures.

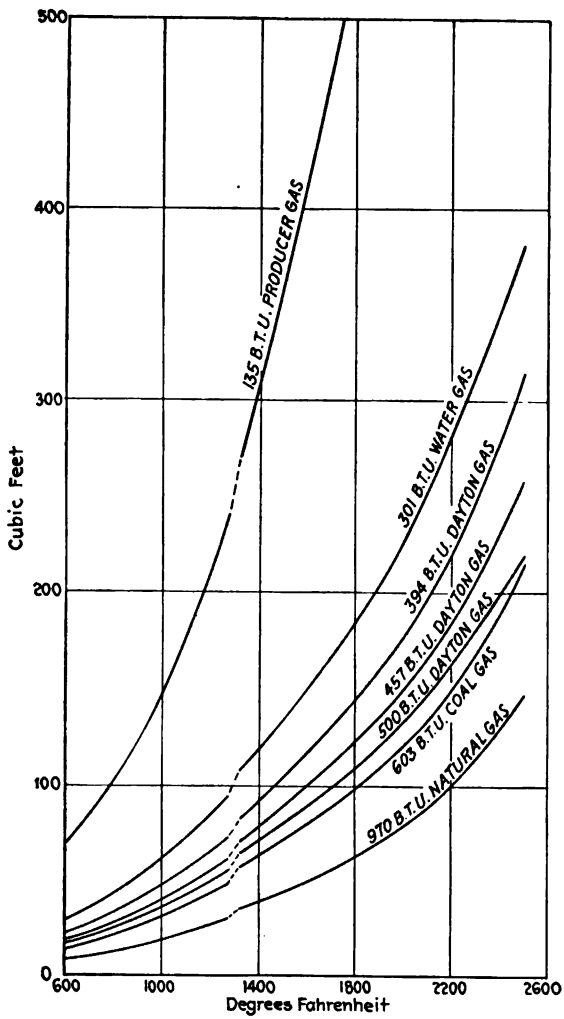


FIG. 334.—Cubic feet of gas theoretically required to heat 100 pounds of iron to the indicated temperatures, based on available B.t.u. calculated from LeChatelier's formulas.

CHAPTER XIX

SURFACE COMBUSTION

By

A. E. Blake*

Surface combustion† is the term applied to the process long recognized as ideal for the oxidation of fuel gases. The name originated in England, where it was applied to the catalytic action of metals, such as platinum and silver and their group members, upon homogeneous explosive mixtures of air and fuel gases, especially when the latter contained free hydrogen. At first, the catalysis was studied at temperatures *below* the ignition point of a mixture. It was observed that, as the temperature of the metal was increased, the reaction was accelerated positively in practically all cases. The metal was used in the massive form instead of in the spongy state.

Bone,‡ McCourt, and others noticed that the speed of reaction became very great when the metal was at a temperature sufficiently high to emit light; also, that at such temperatures nonmetallic substances—such as burnt clay, porcelain chips, and other ceramic material—began to exert an accelerating influence which increased with the increase in temperature of the solid. Whatever may be the influence of the solid at low temperatures, the influence of any solid in granular, porous condition was found to be more and more nearly equal to that of any other, as the intensity of light from the solids was increased. This gave rise to the belief that the influence of sufficiently refractory material would be exceedingly great at temperatures *above* the ignition point, particularly when strongly incandescent. The belief was quickly confirmed. It was found that gaseous reactions could

* Formerly Sales Engineer, Surface Combustion Company, Pittsburgh, Pa.; at present Pittsburgh Representative of The U. G. I. Contracting Co., Philadelphia, Pa., at 928 Union Arcade, Pittsburgh, Pa.

† Process and apparatus covered by United States letters patent and applications for United States letters patent.

‡ William A. Bone, Fuel and Metallurgical Department, University of Leeds, England.

be carried out at rates several million times as great as the ordinary rates of combustion. Efforts were made at once to use the discovery in heating practice. The work naturally led to the use of homogeneous mixtures which contained air and gas in quantitative proportions for complete reaction. Such mixtures are termed *perfect mixtures*, and the reaction is known as *perfect combustion*.

Due to the fact that a perfect mixture is really a true solution of gases, in which the constituents which are to react are in a state of intimate mutual collision, the time required for reaction is what may be termed of molecular dimensions, referring to the time intervals between collisions. Normally, reaction should begin whenever impacts are of sufficient violence to disrupt the molecules. This is the probable status at ignition temperature. However, projection of the gases against large effective areas of incandescent solids subjects them to the ionizing influence of the ultra-violet or short-wave light,* causes increased sensitiveness to molecular impact, and thus promotes greater speed of reaction. Under the conditions stated, reaction is flameless. In describing the process, Bone and his associates made use of the term "flameless incandescent surface combustion."

Prior to the work of Bone, Lucke† employed granular refractory material to assist in combustion when using similar air-gas mixtures. He adopted the term "surface combustion," but in a different sense from that taken by the English workers. A supply of air-gas mixture, in such proportions as to support combustion, issuing from an orifice at a rate of flow exceeding the speed at which combustion is propagated through the mixture, will expand, and the linear speed of all parts of the stream will decrease. At some zone surrounding the orifice, the flow speed will equal that at which combustion is propagated. At this zone, Lucke conceived that combustion would begin, and that the reaction would be complete within a very short distance—hence the term "flame cap," or "surface of combustion." Owing to difficulties experienced in regulation, steady maintenance of the flame cap was impossible and use was made of granular refractory material as a baffle and container for the surface of combustion.

* P. LENARD, Annalen der Physik, ser. 4, 1, p. 498; ser. 4, 3, p. 298.

† CHARLES E. LUCKE, Head of Mechanical Engineering Department, Columbia Univ.

Perfect combustion is the usual aim and attainment in the process being described, and, for that reason, this term has become synonymous with surface combustion. The advantages to be obtained from perfect combustion are self-evident and of great importance.

The gas is consumed completely and the total available energy is released for service.

Since neither air nor gas is in excess, the volume in which the reaction takes place is minimum, and the concentration of energy, therefore, is maximum. In other words, the highest reaction temperature is attained for the fuel being used. The greatest possible difference will exist between the temperature of the products of combustion and the material which it is desired to heat, in which case the rate of heat transfer will be the greatest. By shortening the time of heating, in many classes of work, much heat is saved which otherwise would be lost through the furnace walls in an extended period of firing.

Because of the fact that combustion takes place with no delay, the heat carried by the products of combustion will have the longest possible time to give up heat before leaving the furnace. By way of contrast, attention is called to ordinary methods of firing, in which combustion is not immediate but takes place with the formation of flame, due to the lack of complete mixing of the air and gas, which usually are permitted to enter the furnace in strata. In such a case the rate of combustion will depend upon the rate at which the air and gas diffuse one into the other, bringing within actual range of one another the molecules which are to react. Such a flame may extend the whole distance between the burner and the flue. The products of combustion set free in that portion of the flame near the flue cannot have as long a period to remain within the furnace as those released at the beginning of the flame near the burner; therefore, the possibilities for heat transfer are very much reduced.

With a small reaction zone substituted for the flame commonly used, danger of injury to the work by contact with free oxygen, or with raw gas, is eliminated completely. The space required for this zone is very much less than the space which must be provided for the existence of a flame. Thus surface combustion permits the use of furnaces which have much less internal area, resulting in lower fuel requirements for maintaining the required temperature within a furnace.

Radiation effects secured by the maintenance of flame within a furnace are easily surpassed by the radiation effects secured with proper application of surface combustion, and with less deterioration of the furnace. Flame radiance is due chiefly to the incandescence of carbon particles freed by the early combustion of hydrogen, in the case of hydrocarbons. Under proper conditions, the carbon thus freed is oxidized, in turn, within a brief time. When the conditions are unfavorable, however, the carbon is not consumed entirely. This may be due to the lack of proper concentration of oxygen, in which case the unconsumed carbon loses its heat and luminescence and appears as soot or smoke. This frequently obscures the interior of furnaces and prevents effective radiation to the work. With complete combustion, however, and very high luminosity, much injury to the furnace walls and roof may result—probably on account of the rapidly alternating oxidizing and reducing conditions imposed by the reacting gases in contact with the brick commonly used. When firing with a perfect mixture, the difficulties which have been mentioned do not limit the production of radiant energy. Combustion will be complete and nothing can obscure the furnace interior. Reacting gases cannot come in contact with the furnace walls and cause injury. With the proper use of refractory material in porous, granular form, it is possible to form sources of radiation which are capable of far greater intensity than that of any flame which can be produced. This is common surface combustion practice.

Since the nature and value of radiant energy evidently are not understood generally, it seems well to digress sufficiently to recall a few of the principal known facts and theories relating thereto. The atoms of any glowing solid possess enough vibratory energy to induce wave motion in ether, thus causing production of light. The greater the amount of energy imparted to the solid, the more luminous it becomes; that is, the shorter are the wave-lengths generated in the ether. Regardless of wave-length, light waves travel with the speed of 10^{29} cm. (186,300 miles) per second. Compared with this speed, swiftly moving gases in a furnace are stationary.

The light of longer wave-length is of comparatively slight benefit in the matter of energy transmission, but the shorter waves, particularly those which are responsible for the ultra-violet portion of the spectrum, are of vast importance. Gener-

ally speaking, the whiter the luminosity, the larger the proportion of ultra-violet light produced. Light of short wave-length impinging upon solids, liquids, or gases sets the atoms or molecules in motion. The atoms of a solid are caused to vibrate more rapidly, thus evidencing increased temperature. It is in the form of radiant energy that heat reaches the earth from the sun, since there is no atmosphere known between the two bodies. The various chemical changes involved in plant growth are promoted by sun radiation. Concentration of such radiation by means of a lens serves to illustrate its power to generate heat in solid matter. The beam from a stereopticon can be used to produce similar results.

Heat transfer from gases to solid often may be retarded by the existence of gaseous films at the surfaces of the solid, especially if the surface is not smooth. Langmuir* has shown that such films exist upon the interior surfaces of exhausted incandescent-lamp bulbs. Whatever may be the extent of such influences, it is plain that light waves can penetrate such films with ease.

The use of air in excess of the amount actually required for complete combustion has been regarded as a necessary evil by those who have not made use of equipment such as will be described for the production of a perfect mixture. When employing ordinary equipment and obtaining delayed combustion, as evidenced by the existence of flame within the furnace, it is found necessary to permit the entry of excess air in amounts sufficient to prevent the flame from extending into the flue. It is a case of increasing the rate of a reaction by increasing the concentration of a component. In other words, excess air makes certain that the gas will be promptly overwhelmed and completely consumed before leaving the furnace. In such cases, however, energy is absorbed by the non-reacting air in coming to the temperature of the gases entering the flue. The amounts of energy thus prevented from doing useful work within a furnace can be found by inspection of Fig. 339. An excess of 50 per cent of air used with the gas mentioned, when operating at 2,500°F., will absorb 23.5 per cent of the total heat liberated by the reaction.

Figure 340 shows the objection to the use of excess air in the surface combustion process. Homogeneous mixtures containing excess air cannot react as rapidly as perfect mixtures, because of the simple mechanical hindrance of inert molecules.

* Irving Langmuir, *J. Am. Chem. Soc.*, **37** (1915), 1139–1167.

Neither can such mixtures react within a space as small as will suffice for a perfect mixture. The resultant reaction tem-

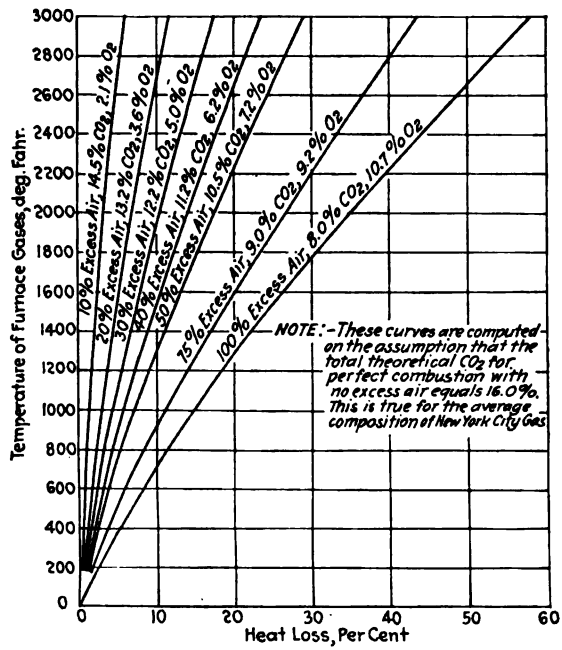


FIG. 339.—Heat loss in flue gas due to excess air at various temperatures.

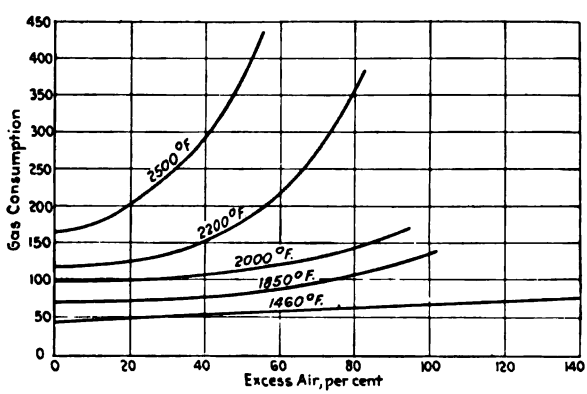


FIG. 340.—Influence of excess air in burning homogeneous mixtures of air and gas.

perature is lowered; therefore, greater amounts of gas must be burned if it is desired to hold a given temperature in any case.

A small surface combustion furnace was used in securing the data.* It will be noted that, while holding the temperature of 2,500°F. with a perfect mixture, 163 cu. ft. of gas per hour were required. While holding the same temperature with 40 per cent excess air, 300 cu. ft. per hour were required.

It is a well known fact that the theoretical reaction temperature of a producer gas, without preheating, may be 1,000°F. lower than in the case of gases composed entirely of combustible matter. In consideration of the above evidence, and the fact

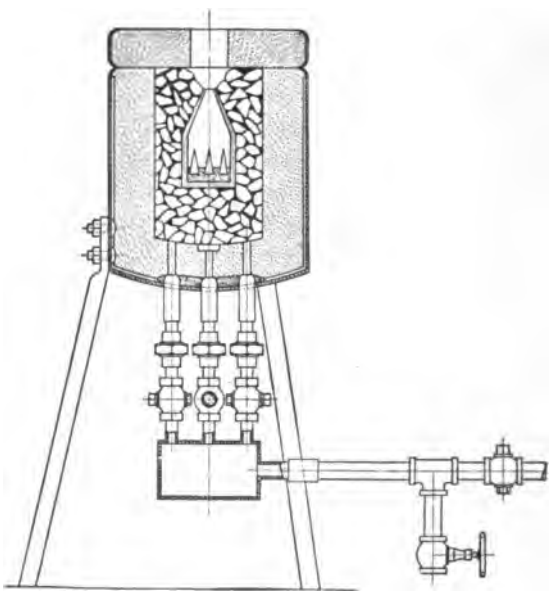


FIG. 341.—Early type of surface combustion furnace.

that producer gas usually contains about 60 per cent of nitrogen, the reason is not difficult to see.

The detrimental effect of quantities of free oxygen within a furnace are too well known to require comment. It is considered so serious as to cause the use of vast quantities of excess gas in certain steel-mill operations, such as annealing, and in the heating of sheet bars and sheets for rolling. It has recently been demonstrated that the use of a perfect mixture in such work

* LELLEP, Am. Gas Assn., *Minutes, Commercial Section*, **1919, 290; 1920, 235.**

results in a saving of about 60 per cent of the amount of fuel customarily used.

Apparatus for the production and use of perfect mixtures is designed in accordance with the nature of the heating to be done and the gas to be used.

Figure 341 shows an early type of surface combustion furnace which has again come into use for high-temperature fusion testing. Within the crucible, located as shown, nearly pure alumina has been fused. Homogeneous air-gas mixture enters the refractory bed from below. At the zone where the flow is retarded to a rate equal to the rate of combustion propagation, reaction takes place. Above the zone, heat is absorbed from the products of combustion until the granular material has approximately the same temperature as the gases themselves.

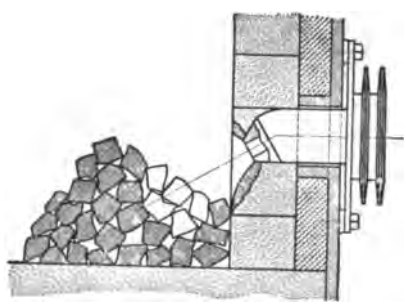


FIG. 342.—Impact-type burner using refractory bed.

The underfired refractory bed is unsuited for ordinary heating because of the difficulty in keeping the supply ports open. This difficulty has been overcome, as shown in Fig. 342. This illustrates a delivery tube of special design in position to project a perfect mixture into a pocketed bed of refractory. The zone of combustion forms at the points within the bed at which the flow speed equals the rate at which combustion will propagate itself. The liberated products of combustion containing the energy set free by the reaction find their way out of the bed and through the furnace. The bed becomes incandescent soon after starting, and the products of combustion will issue from it at the temperature of the solid material. At incandescence, the radiation is in position to increase the rate of combustion. Due to higher refractory qualities of the material composing the bed, it can be maintained at a state of incandescence greater than that of any flame which can be tolerated by the furnace lining.

In low temperature work, it is customary to use this radiation indirectly rather than directly. The result is a very high degree of uniformity in temperature. The furnace interior is entirely free from flame or other obscurity. This application is in very extensive use, especially in heat treating, tinning, galvanizing, etc.

It is to be noted that the delivery tube, commonly referred to as the burner, is cemented tightly into the furnace wall. No air can enter except by the orifice, and no gases can escape at this point. The tube is designed to be self-cooling. The orifice is constricted, to accelerate the flow of mixture to a rate exceed-

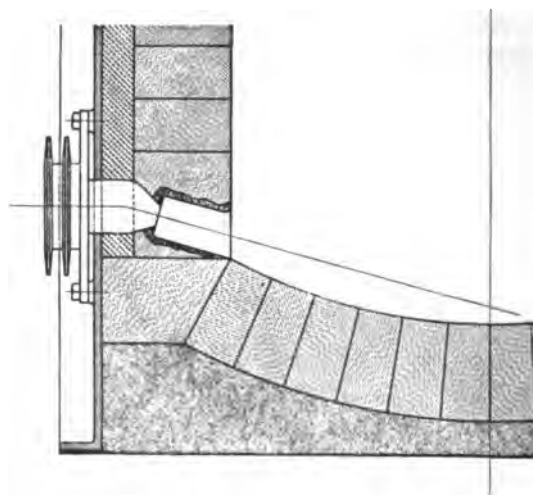


FIG. 343.—Tunnel burner of the arch type.

ing the speed of combustion propagation, as long sa the flow pressure is greater than 0.2 in., water-gage. Due to the positive pressure continually exerted within the furnace, the products of combustion are swept from the interior to the flues without the assistance of stack draft, which is actually detrimental in surface combustion practice.

Figure 343 shows an application which has extensive use in glass melting, forging, shaping, welding, melting metals, sheet and pair heating, etc. The mixture is delivered from the metal nozzle to the base of a refractory cement-lined recess in the furnace wall. A portion of the expanding gases is retarded by the friction with the tunnel surface. Upon igniting, a small amount of the mixture

burns within the tunnel, at its surface. The remainder burns outside, in the furnace chamber. The tunnel surface is heated rapidly to incandescence, however; and, when in that condition, combustion within the furnace chamber is no longer in evidence. Recalling the ionizing influence of radiant energy, and the speed at which it is transmitted, it is probable that combustion of the already potentially reactive mixture is complete within the tunnel. The location and direction of such tunnels will depend upon the numerous special factors involved in each case. Radiation effects are secured by permitting the products of combustion to sweep the roof or other portions of the furnace interior. Experience has shown to what extent this can be done with safety to the lining.

Several other types of burner are in use. Self-cooling or air-cooled types are commonest, but occasionally water cooling is used.

The importance of uniformity of temperature in industrial furnace work is very often paramount. It is secured in the simplest manner. In general, burners of equal size, equally spaced, and equally supplied with perfect mixture, will solve the problem.

The factor of highest importance in the perfected surface combustion process is the production of perfect mixture, or of any desired mixture, to produce essential conditions within furnaces. Figure 344 shows one type of automatic proportioning and mixing device, attached to the manifold upon a furnace. It is called the low-pressure system.

Air is supplied at a maximum pressure of about 1 lb. per square inch; it is governed in flow by the upper of the two cocks. Entering the chamber shown, it passes thence through a venturi tube to a manifold supplying the burners. A nozzle is located within the throat of the large tube. The nozzle can be adjusted with a screwdriver and secured by a locknut. The location of the nozzle in the large tube determines what proportion of air and gas will form the mixture. So long as the composition of the gas remains constant, no change in the position of the nozzle is necessary. Raising the nozzle increases the proportion of gas in the mixture. It is a simple matter to make the adjustment which will produce a perfect mixture. In operation, air creates suction upon the nozzle. Gas is drawn from a small governor which receives it at any pressure from one to about eight ounces. The function of the governor is the delivery of gas at constant atmospheric pressure at all times, regardless of the rate of flow. With

the gas cock closed, and air flowing, reduced pressure is produced in the governor and its connections, due to suction upon the



FIG. 344.—Furnace with low-pressure automatic proportioner.



FIG. 345.—Furnace with high-pressure automatic proportioner.

nozzle. Atmospheric pressure will move the diaphragm inward and cause the entry port for gas to open fully. When the gas is

turned on, the gas pressure within the governor will exceed atmospheric pressure for the moment, due to the flow resistance of the nozzle, and cause the diaphragm to move outward, drawing the slide-valve attached to it over the gas port, to a position where flow to the nozzle will continue at atmospheric pressure. Changing the air supply will automatically change the gas supply to insure constant proportion throughout the range of

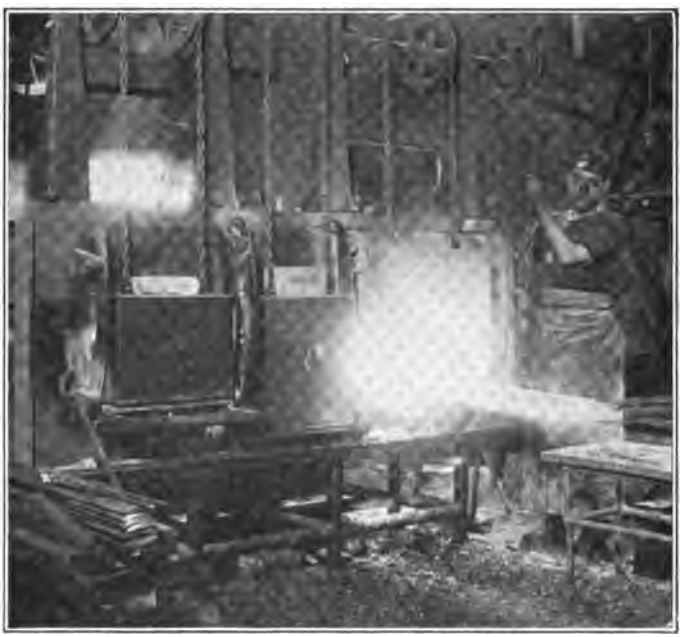


FIG. 346.—Surface combustion welding furnace with central preheating chamber, Lowell, Mass. City gas used as fuel.

the device. During operation, the gas cock never is touched, but remains wide open. The convenience and economy of single valve control are obvious. Convenient for observation, a water gage located upon the burner manifold, for the assistance of the operator in determining the rate of firing.

Figure 345 shows another device for automatically forming and supplying perfect mixture. It is called the high-pressure system. Suitable means are provided for supplying the gas at the requisite pressure; the pressure required varying with the gas used. One and one-half ounces per square inch is satisfactory for blast-furnace gas, while 8 ounces or 1 pound will suffice for



FIG. 347.—Surface combustion day tank for melting very refractory glass. Natural gas is used as fuel.



FIG. 348.—Surface combustion annealing furnace of car-bottom type for 40,000-lb. charges of rifle parts. Closed annealing boxes were dispensed with. Coke-oven gas is used as fuel.

producer gas. Coke-oven gas can be used at from 3- to 10-lb., and natural gas at from 10- to 20-lb. pressure.

In many cases both natural and artificial gases are available at the right pressure. When such is not the case, a compressor is used. Gas is conducted under pressure to the apparatus. For proper control over the rate of firing, a valve and gage are provided, as shown. Gas is projected through a nozzle into the

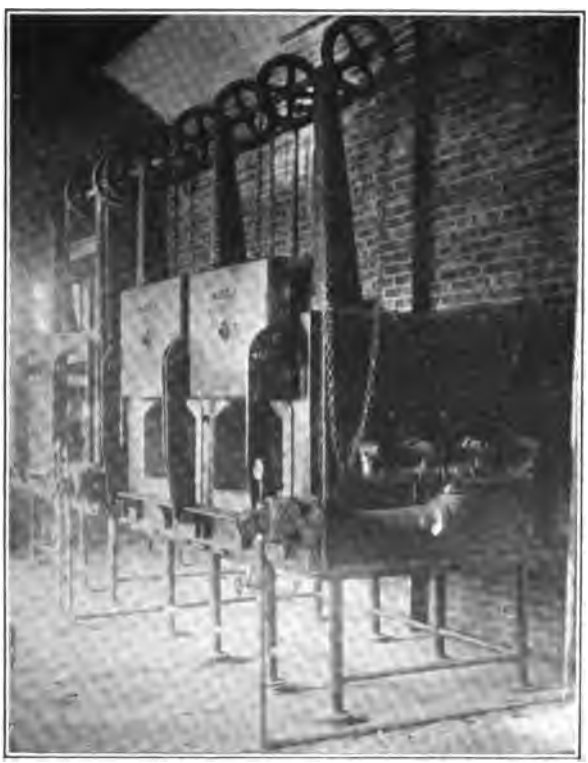


FIG. 349.—Surface combustion carbonizing furnace.

throat of a venturi entraining tube. Flow energy, or inertia of the gas, causes the entrainment of the air necessary for combustion through the ports shown. Proper selection of the gas nozzle and accompanying adjustment of the shutter by which the area of the air ports is varied, will enable the production of a perfect mixture, or of one which is rich or lean, as may be desired. When the desired setting once has been made, the proportion of air and gas will remain true and constant throughout the



FIG. 350.—Surface combustion continuous sheet galvanizing kettle; coke superseded by city gas.



FIG. 351.—Surface combustion galvanizing kettle. Coke-oven gas fuel.

range of the apparatus, which is usually about four to one. The mixture becomes homogeneous at about the time it leaves the

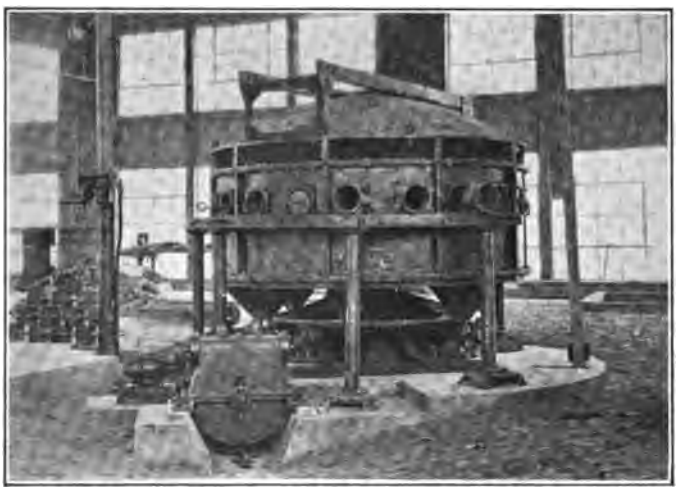


FIG. 352.—Surface combustion swaging or nosing furnace for six-inch shell, Frankford Arsenal. The shells rotate in place and the entire furnace revolves; output, 120 shells per hour.

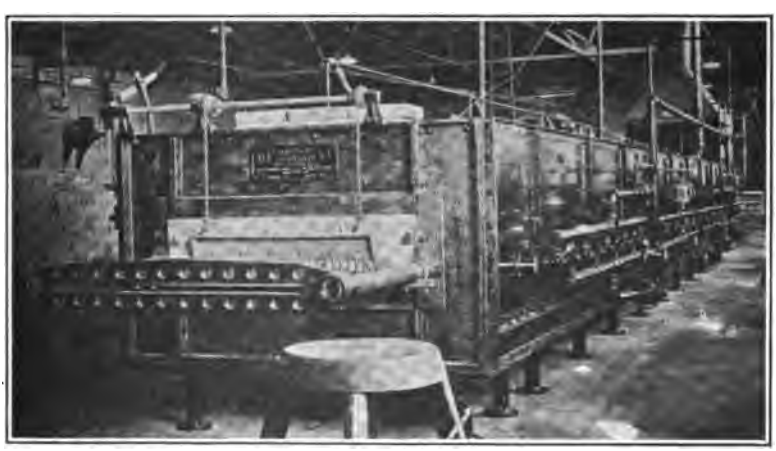


FIG. 353.—Surface combustion wire patenting furnace—intake end.

entraining tube to enter the manifold. This system* does away with the necessity for air under pressure, and the consequent

* The Franklin Institute, Phila., Pa., acting through its Committee on Science and the Arts, investigating the jet entraining apparatus of The Surface Combustion Co., has awarded to the inventor, W. BARTON EDISON, the Edward Longstreth medal of merit (April 6, 1921).

air piping, with all moving parts, such as a governor; also with any provision for draft for either the high- or the low-pressure system.



FIG. 354.—Surface combustion wire patenting furnace—delivery end.



FIG. 355.—Battery of surface combustion heat treating furnaces for quenching and drawing cannon tubes, Watertown Arsenal. Boston city gas used as fuel.

No decisive steps have been taken, as yet, in the matter of preheating air and gas either separately or combined. This is

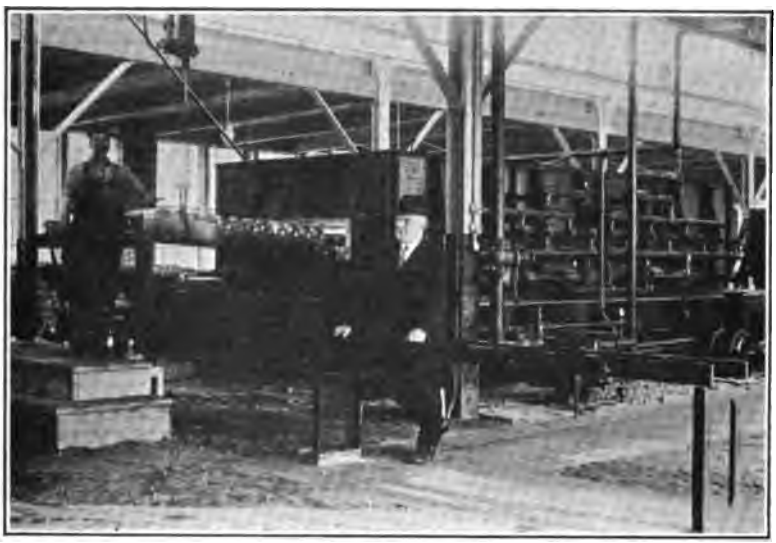


FIG. 356.—Automatic surface combustion shell-quenching furnace, Pawtucket, R. I. City gas used as fuel.

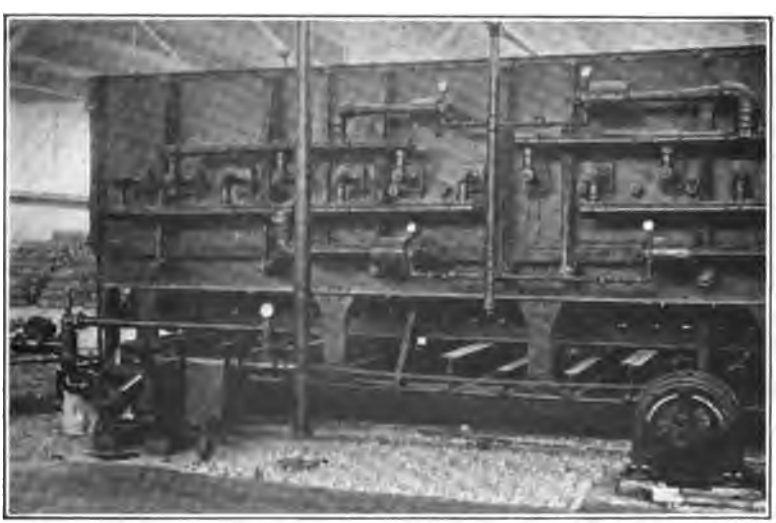


FIG. 357.—Automatic surface combustion shell-drawing furnace, Pawtucket, R. I. City gas used as fuel.

due partly to the lack of any difficulty in securing the highest temperatures which furnaces will withstand, and to the probable



FIG. 358.—Incomplete interior of installation shown in Fig. 357.

difficulty to be looked for in avoiding premature ignition. In several instances which have come to the notice of the author, sur-



FIG. 359.—Surface combustion tinning pot—one of a battery of 40. Coke-oven gas used as fuel.

face combustion furnaces have equalled in efficiency the fuel consumption of furnaces operating with preheated air, and have even



FIG. 360.—Battery of surface combustion lead-melting furnaces for continuous melting in an electrotype shop. City gas used as fuel.



FIG. 361.—Small surface combustion forge.



FIG. 362.—Surface combustion rivet heater; width of opening, 5.5 inches; output 100 pounds per hour.

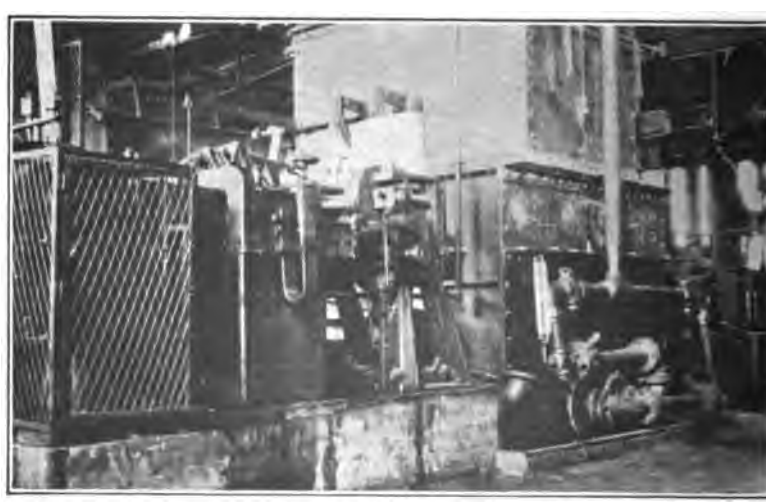


FIG. 363.—Continuous forge furnace. High-pressure system, using producer gas at about eight ounces pressure.



FIG. 364.—Furnace interior of installation shown in Fig. 363.

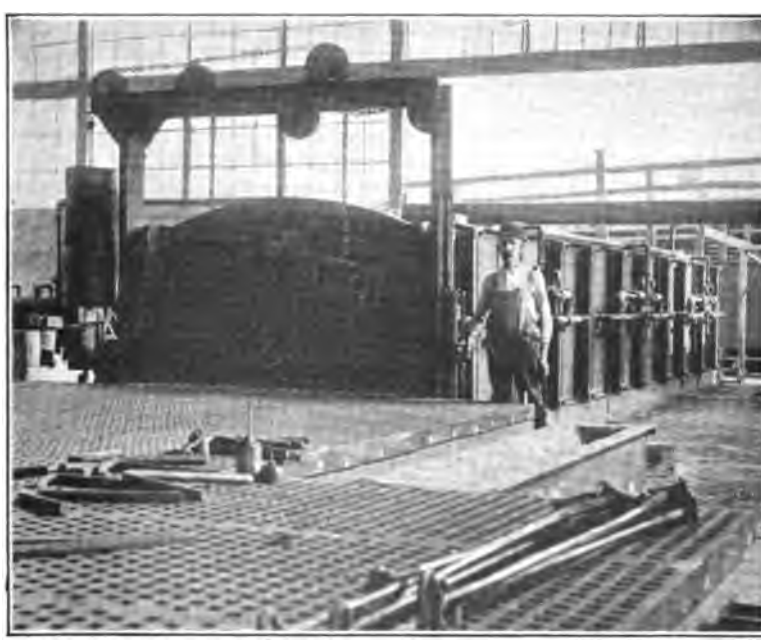


FIG. 365.—High-pressure system, using city gas. Hot shaping furnace for heating ship steel.

made fuel savings of at least 40 per cent. The surface combustion process has won the support of numerous municipal gas companies and public service corporations, since it has enabled them to secure industrial consumers of gas and to hold them in the face of keen competition with other fuels as regards cost. This has been possible through the unsurpassed economy in the use of the gas.

The accompanying illustrations present certain examples of furnace engineering, selected to give the reader some idea of the industrial application of surface combustion. Steam generation by this process has received little attention in this country thus far, but very remarkable results have been attained in England, and it is altogether probable that greater activity will occur in that line of work in the near future in the United States.

Due to rather frequent requests for a definition of surface combustion, the author has prepared the following; it is given with the hope that it may prove of enough value to some readers to warrant its inclusion:

The term surface combustion, insofar as it relates to heating problems, should merely refer to the well known influence of light-wave energy upon gas mixtures to accelerate chemical reaction. In other words, it is light catalysis of gas reactions. (For authority to use the term catalysis in this connection, see "Catalysis in Theory and Practice," by ERIC K. RIDEAL and HUGH S. TAYLOR, Macmillan, London, 1919; Chapter 13, pages 410–436.)

Surface combustion, therefore, can and does take place in any gas reaction zone wherever there is enough light-wave energy to affect the speed of reaction by ionization of molecules, breaking up molecules, or otherwise changing their condition to facilitate more rapid readjustment.

Surface combustion is not new. The means for increasing surface combustion *to the maximum* in any given zone, together with the realization of the advantages to be gained from doing so, should be credited to Bone, Lucke, and their associates; to the past and present personnel of the Surface Combustion Company, and to any others who, like the above, have done anything towards achieving the conscious or unconscious goal, namely, *perfect combustion* (or, to allow for the influence of atmospheric conditions and requirements within a furnace, perhaps it would be better to say *quantitative combustion*, involving exact, predetermined, or variable at will, proportioning of air and gas to create the desired furnace conditions within attainable limits), and who have evolved such means for so doing that realization is possible and practical *in the hands of ordinary workmen.* Nothing can be claimed for mere surface combustion; but either perfect combustion or quantitative combustion may have advantages which place them alone and unrivalled in the field of gas utilization.

A bibliography of the subject of surface combustion is appended.

BIBLIOGRAPHY

Books

BONE, WILLIAM ARTHUR, "Coal and Its Scientific Uses." London: Longmans. **1918.**

Contains a chapter on the surface combustion system developed by Bone.

DONATH, E., and LANG, A., "Ueber Oberflächenverbrennum gund Flammenlose Feuerungen." Berlin: Verlag für Fachliteratur. **1913.**

Journal Articles

COURIOT, and MEUNIER, JEAN, "Action d'un Conducteur Électrique Incandescent sur les Gaz qui l'Entourent." 1907. *Comp. rend. des Sèances de l'Acadèmie des Sciences*, **145**, 1161–1163.

MEUNIER, JEAN, "Sur la Combustion par Incandescence des Gaz en Presence des Corps Oxydables et des Corps Incombustibles." 1908. *Comp. rend. des Sèances de l'Acadèmie des Sciences*, **146**, 757–758.

MEUNIER, JEAN, "Sur la Combustion sans Flamme et l'Inflammation des Gaz a l'Extremité d'une Tige Metallique." 1908. *Comp. rend. des Sèances de l'Académie des Sciences*, **146**, 539–540.

MEUNIER, JEAN, "Sur la Combustion sans Flamme et sur son Application a l'èclairage par les Manchons Incandescents." 1908. *Comp. rend. des Sèances de l'Acadèmie des Sciences*, **146**, 864–866.

BONE, WILLIAM ARTHUR, "The Influence of Surface upon Gaseous Combustion." 1909. *J. Gas Lighting*, **106**, 300–303.

MEUNIER, JEAN, "Sur la Combustion des Gaz sans Flamme et sur les Conditions d'Allumage par Incandescence." 1909. *Comp. rend. des Sèances de l'Acadèmie des Sciences*, **148**, 292–294.

MEUNIER, JEAN, "Sur la Combustion des Gaz sans Flamme et sur les Conditions d'Allumage par Incandescence." 1909. *Comp. rend. des Sèances de l'Acadèmie des Sciences*, **148**, 292–294.

BONE, WILLIAM ARTHUR, and WILSON, J. W., "Combustion of Mixed Gases." English patent 25808, Nov. 7, 1909; "Combustion of Gaseous Fuel," English patent 29430, Dec. 16, 1909. *J. Soc. Chem. Ind.*, **29**, 1448.

BONE, WILLIAM ARTHUR, "Surface Combustion and Its Industrial Applications." 1911. *Engineering*, **91**, 487–489.

KERSHAW, JOHN B. C., "Flameless or Surface Combustion." 1911. *Met. Chem. Eng.*, **9**, 628–630.

MEUNIER, JEAN, "Sur la Combustion Vive des Gaz sans Flamm on Combustion Convergente." 1911. *Comp. rend. des Sèances de l'Acadèmie des Sciences*, **152**, 194–196.

"Surface Combustion." 1911. *Power*, **34**, 787–788.

"Surface Combustion in a Boiler." 1911. *Power*, **34**, 787–78.

"Application of Prof. Bone's Boiler." 1912. *Power*, **35**, 80–81.

BENNER, RAYMOND C., "Surface Combustion." 1912. *Min. Sci. Press*, **104**, 336–337.

BERTHIER, A., "La Combustion Catalytique et ses Applications Industrielles." 1912. *La Lumiere Électrique*, 1912, ser. 2, **19**, 36–243.

BLACKWELL, H. C., "Surface Combustion." 1912. *Am. Gas L. J.*, **97**, 90–92. *Chem. Eng.*, 1912, **16**, 91–93.

BONE, WILLIAM ARTHUR, "Flammenlose Oberflächenverbrennung." 1912. *Stahl und Eisen*, **32**, 1095–1098.

BONE, WILLIAM ARTHUR, "Gas Combustion at Hot Surfaces." 1912. *Eng. News*, **67**, 96–97.

BONE, WILLIAM ARTHUR, "Oberflächenverbrennung." 1912. *Chemiker Zeitung*, **36**, 1440 and 1445–1446.

BONE, WILLIAM ARTHUR, "Surface Combustion." 1912. *J. Franklin Inst.*, **173**, 101–131.

BONE, WILLIAM ARTHUR, "Surface Combustion and Its Industrial Applications." 1912. *J. Gas Lighting*, **118**, 432–434. *J. Soc. Chem. Ind.*, **31**, 524–525.

ELLIS, CARLETON, "Flameless Combustion." 1912. *Trans. Am. Inst. Min. Eng.*, **43**, 612–630. *Smithsonian Inst. Report*, **1913**, part 1, 639–652.

"Surface Combustion." 1912. *J. Ind. Eng. Chem.*, **4**, 77–79.

BEMENT, A., "Flameless Combustion." 1913. *Power*, **37**, 27.

BERGER, CLEMENT, "Nouveau Mode de Chauffage par les Gaz Combustibles." 1913. *Revue Générale de Chimie Pure et Appliquée*, **16**, 117–122.

BLUM, RICHARD, "Die Flammenlose Verbrennung und Ihre Bedeutung für die Industrie." 1913. *Z. Ver. Dtsch. Ing.*, **57**, 281–286.

BONE, WILLIAM ARTHUR, "Surface Combustion." 1913. *J. Gas Lighting*, **121**, 242–246.

BUNTE, HANS, "Flammenlose Oberflächenverbrennung." 1913. *J. Gasbel.* **56**, 853–859.

KRULL, FRITZ, "Die Flammenlose Oberflächenverbrennung." 1913. *Z. Ange. Chem.*, **26**, Aufsatzteil, 401–404.

LUCKE, CHARLES EDWARD, "Design of Surface Combustion Appliances." 1913. *J. Ind. Eng. Chem.*, **5**, 801–824.

MCCOURT, C. D., "The Bonecourt Process of Surface Combustion." 1913. *Electrician*, **71**, 132–135 and 171–173.

MACHE, HEINRICH, "Uber die Sogenannte Flammenlose Gasheizung." 1913. *Z. Angewa. Chem.*, **26**, Aufsatzteil, 167–168.

NEUMANN, B., "Flammenlose oberflächenverbrennung." 1913. *Stahl und Eisen*, **33**, 593–599.

TECLU, NIC., "Zur Kennzeichnung der Flamme." 1913. *J. Prat. Chem.*, new ser., **88**, 189–192.

BONE, WILLIAM ARTHUR, "Surface Combustion." 1914. *Engineering*, **97**, 356–357.

BONE, WILLIAM ARTHUR, "Surface Combustion." 1914. *J. Roy. Soc. Arts*, **62**, 787–796, 801–811, and 818–827.

DOBBELSTEIN, O., "Ueber die Flammenlose Oberflächenverbrennung." 1914. *Stahl und Eisen*, **34**, 561–573.

GRAY, H. H., "A Critical Review of Flameless Incandescent Surface Combustion." 1914. *J. Gas Lighting*, **126**, 786–789.

NAITO, A., "Suggested Application of Surface Combustion to Carbonization of Coal." 1914. *Am. Gas Lt. J.*, **100**, 187–188.

BRADFORD, J. L., and CORWIN, C. D., "Some Recent Experiments in Surface Combustion." 1915. *Power*, **42**, 787–788 and 855–859.

BONE, WILLIAM ARTHUR, "Flame and Flameless Combustion." 1916. *J. Gas Lighting*, **135**, 515–518.

"Heat-treating Plant Using Surface Combustion." 1916. *Met. Chem. Eng.*, **15**, 363–364.

LATTA, NISBET, "Three Principal Difficulties Presented in the Use of the Surface Combustion Principle for the Gas Firing of Boilers." 1916. *Am. Gas Lt. J.*, **105**, 225–229.

RICHARDSON, CHARLES E., "Artificial Gas-fired Furnace Installation." 1916. *J. Ind. Eng. Chem.*, **8**, 911–914.

SCHRAMM, E., and CAIN, J. R., "A Test of a Surface Combustion Furnace." 1916. *J. Ind. Eng. Chem.*, **8**, 361–365.

THOMAS, J. D., "Surface Combustion for Domestic Uses." 1916. *Gas Age*, **37**, 669–670.

BANCROFT, WILDER D., "Contact Catalysis II. Fractional Combustion." 1917. *J. Phys. Chem.*, **21**, 644–675.

BARTLETT, JOHN H., "Producer Gas Takes Place of Oil for Continuous Forging Operation in Buffalo Plant." 1917. *Am. Gas Eng. J.*, **107**, 49–51.

DE GHEQUIER, A. J., "Preheating Effect Secured by Combining Functions of Hopper, into Which Pieces to be Treated are Charged, with Flue in Gas-fired Furnace for Small Steel Forgings." 1917. *Am. Gas Eng. J.*, **107**, 277–278.

HARRIS, WILLIAM J., JR., "Gas for Heating Galvanizing Bath Meets Coke Fuel Cost." 1917. *Am. Gas Eng. J.*, **106**, 338–340.

HARRIS, WILLIAM J., JR., "Tin Plating with Coke-oven Gas." 1917. *Iron Age*, **100**, 1417–1419.

PILNACEK, EDWARD A., "Flash Annealing Large Projectiles by Gas." 1917. *Am. Gas Eng. J.*, **107**, 97–98.

READ, HENRY L., "Advantages of Gas for Production of Varnish Make Its Installation Highly Advisable in Many Cases." 1917. *Am. Gas Eng. J.*, **106**, 97–98.

READ, HENRY L., "100 Lb. of Coffee Roasted at Fuel Cost of 7 Cts. for Gas." 1917. *Am. Gas Eng. J.*, **106**, pp. 489–490.

READ, HENRY L., "Results of Tests of Gas-burning Systems in Oil Cracking Installation Show Need of Careful Study of Industrial Fuel Tasks." 1917. *Am. Gas Eng. J.*, **106**, 29–30.

READ, HENRY L., "Some Results of Recent Work in Surface Combustion." 1917. *Power*, **45**, 225–226.

READ, HENRY L., "Successful Operation of Optical Pyrometer Calibrating Furnace Proves That Gas can be Efficiently Applied to Temperatures up to 3,000°F." 1917. *Am. Gas Eng. J.*, **106**, 409–410.

READ, HENRY L., "Tests Demonstrating Adaptability of Gas to Melting of Soft Metals." 1917. *Am. Gas Eng. J.*, **106**, 49–50.

RICHARDSON, CHARLES E., "Gas-fired Welding Furnace." 1917. *Iron Age*, **100**, 422–423.

RICHARDSON, CHARLES E., "Installation Made for Welding Tool-steel Face on Soft-steel Slab for Rotary Cutter Knives Demonstrates Availability of Gas for Such Work." 1917. *Am. Gas Eng. J.*, **107**, 145–148.

of the time, much of the apparatus necessary to produce and distribute was left idle and unproductive on the investment. It was essential, therefore, that attention be given to developing uses for gas at other than lighting hours. Although for many years various crude appliances were used in small numbers for cooking and water heating, it was not until 1880 that gas came into popularity for domestic cooking, thus causing a demand preceding the meal hours. This field has been developed actively and today the sale of gas for cooking is one of the profitable phases of the industry. About 1890 water heaters were brought into general use and their development further improved the load factor. With lighting, cooking and water heating there still remained valleys in the load curve, especially in the mid-morning and mid-afternoon hours and during the night.

Even under rather favorable conditions of selling gas for domestic cooking, lighting and water heating, the gross earnings per year on the value of the property and equipment of a large percentage of gas properties, are only about 20 per cent. Contrasted with this, manufacturers generally expect and indeed receive gross earnings per year of from three to five times the investment in plant and equipment. These data indicate the large overhead that is unavoidable in such a business as that of supplying gas for city uses, and they show the need for developing long hour business and thus increasing the earnings on the capital involved.

A gas distribution system must be built adequate to take care of the peak hour. It is apparent that, if as much gas could be sold in each hour as during the peak hour, the daily output would be 24 times the peak hour and the distribution system would be working to 100 per cent capacity, producing the maximum of return on the investment. At present, however, in communities where gas is supplied for lighting and domestic service, the total daily output is only about nine times the amount of the peak hour. Therefore, there remains a big possibility of adding business to the offpeak hours by increasing investment in production equipment only. It is this thought of securing the greatest use of the plant and distribution system, and consequent greatest return on the money invested, that must be borne well in mind in the greater development of the artificial gas industry. Furthermore, gas generating equipment so far developed does not lend itself to producing gas at a low cost and also at widely varying rates of generation.

Therefore, among the problems to be solved is that of designing and building generating apparatus adaptable to the production of gas at variable rates and reasonable costs, and securing business that will make the rate of consumption approximate the rate of production.

About the year 1900 there was begun in a very modest way an effort to encourage the use of manufactured gas for industrial purposes. It was natural that it should first be applied to restaurant and hotel cooking, candy making, small metal heating processes, etc. This class of business proved to be profitable and indicated some of the great possibilities in the broader field.

Artificial gas as a medium for heat in the industrial world, and to an increasing extent for household purposes, is waiting ready to be used on a vast scale as rapidly as the problems that influence it are solved. This is an age that demands domestic conveniences and manufacturing efficiencies. The people want for their homes the improvements that cause the least drudgery and are willing to pay for them. The manufacturer wants in his shops the most modern and efficient methods and practices, and gladly accepts them as they are developed and presented to him. There is no medium greater than gas in the possibilities for providing comfort in the home and more efficient heat utilization in the manufacturing world. If one reviews the great success attained by the use of natural gas for all sorts of household and industrial purposes, arguments need not be offered to prove that manufactured gas can serve a similar purpose when properly developed and applied in all its phases. In nearly every instance where it has been exploited for any length of time, natural gas is bordering on exhaustion and it is necessary to secure some medium to replace it. Doubtless, the general belief is that the vast stores of coal can be called upon to supply fuel to take the place of the waning natural gas. This is, of course, true to a considerable extent. However, a lesson must be learned from the costly results of the extravagant waste of natural gas that prevailed for many years. Had it been conserved and carefully utilized, it would have lasted several decades longer. Sooner or later the great deposit of coal will become exhausted; and even though that time is not now imminent, nevertheless a strong concerted effort should be made to reduce greatly

the tremendous waste that results in burning particularly bituminous coal, as it generally is practiced to-day. Otherwise some coming generation will see the passing of coal as we see the passing of natural gas.

The percentage of efficiency derived from burning bituminous coal for general household and industrial purposes is low. This is caused largely by the fact that it is practically impossible to regulate the air supply to support combustion properly through the process of burning. When coal is fired on to a hot fuel bed, there is a very rapid evolution of the volatile matter and the air supply at that period should be sufficient to support the complete combustion of these volatiles. The air supply should diminish gradually as the volatiles are evolved and finally be only sufficient to support efficient combustion of the resultant carbon. It is almost impossible to accomplish this, and the result is that a large percentage of the volatile matter of the coal passes off through the chimney and thus wastes valuable products.

Unless coal is distilled, nearly all the volatile by-products are either extravagantly consumed or pass off as smoke—an absolute waste. The World War brought to our attention the weakness of the United States in the dye, chemical and explosives industries. The principal source of materials required for the manufacture of these products lies in the by-products derived from the destructive distillation of bituminous coal. There is reason to believe that a lesson has been learned and that in the future the dye and chemical industries will be fostered and exploited. Their adequate development will create a demand for the by-products of coal and tend to reduce the net cost of gas making. It is therefore highly essential that bituminous coal should be treated by destructive distillation—carbonization—to obtain its numerous products and that each product be developed and applied to serve the greatest purpose. In the gas should remain only those compounds not of greater value out of it. Although to accomplish this is a much greater problem than the mere mention of its possibilities, nevertheless the realization of its necessity should be a stimulus to the solution of the problem. There is no reason to believe that apparatus cannot be designed and built to carbonize even the poorer grades of coal and thus secure, besides gas and possibly some coke, the great number of valuable by-products with their derivatives.

It is a well-known fact that coal fields are not distributed equally throughout the United States, nor is the quality and composition of the various deposits similar. In gasifying coals, it is found that widely variant results are secured from the various grades. It is not practicable to produce from a given coal, gas of broad range of B.t.u. per cubic foot, nor can equal heating value gas be secured from all different coals. Pennsylvanian coals generally are considered the best and produce a good yield of rather high-heating power gas. On the contrary, many coals from Ohio, Illinois, Dakota, Kansas, etc., are not suitable for making gas of a heating value of 600 B.t.u. per cubic foot or thereabouts. If a specification for gas of 550 to 600 B.t.u. per cubic foot is required in districts where good gas coal is not available, it causes the following of the uneconomic procedure of paying high transportation charges to bring certain coals or other gas-making materials long distances, to comply with arbitrary regulations. It is better economics to permit each locality to use the process best suited to the materials available and let the gas be what it may. Corresponding adjustment can be made so that it will be sold at a price of benefit to all concerned. Certain sections will no doubt find it more practicable to convert even non-coking coals to low B.t.u. gas and sell at a corresponding price than to bring in special gas coals, oil, etc., from a long distance and pay the transportation charges. These transportation costs must enter into the selling price and will almost certainly cause it to be much higher in proportion to the efficiency of utilization than would be the low B.t.u. gas made from local materials. To permit gas companies the use of the process and materials that will make gas at the lowest cost is a distinct advantage to all classes of customers. The correspondingly low selling price that can be made stimulates the use of gas for industrial purposes. Such a condition transfers a part of the fixed charges to the industrial customers, thus reducing this item for the domestic customer and causing their rates to be lower than they otherwise would be.

The question of standards of gas quality enters here again. Several years ago the gas mantle was developed and rapidly came into popularity to displace the old open-flame gas burner. The result is that today only a negligible percentage of gas is used in open tips and the standard based upon candlepower may be considered obsolete. For all other purposes than open

flame lighting, heat units are the basis of the value of gas. Therefore, during the past decade practically all public utility regulatory bodies have adopted as the artificial gas standard a fixed number of B.t.u. per cubic foot. This specification generally ranges from 528 to 600 in the different States.

However, the regulation calling for a fixed number of B.t.u. per cubic foot has given gas companies little latitude in their methods of producing gas, and, to a considerable extent, has caused output costs to be unduly high in certain localities. The result has been that the impression has prevailed that, because of its comparatively high cost of production, gas cannot be sold on a large scale for industrial purposes. There is ample reason to believe that such a condition need not exist, and, in fact, there are a number of instances of the use of manufactured gas on a very large scale for industrial purposes. In these cases careful study has been made of efficient heat application and combustion, and under such conditions gas is sold at a price that is satisfactory to the consumer and at the same time yields the gas company a fair profit. Its application has been especially successful in metal treatment through a wide range of temperatures and purposes.

The full development of manufactured gas for general industrial—and probably house-heating—purposes will be stimulated greatly when gas companies and the regulatory bodies work out the correct standards, taking into consideration all features affecting the situation. Experience has demonstrated that 550 to 600 B.t.u. gas—a rather generally accepted standard—is not necessarily the most efficient of utilization. In England, where the war precipitated a readjustment of standards permitting a greater latitude in heating value, it has been found that the interests both of the producer and consumer are well served by a low B.t.u. gas—400 to 450. When 600 B.t.u. gas is made by either a coal gas or a carbureted water gas process, it is necessary to retain in the gas, to maintain that standard, a quantity of hydrocarbons, etc., that add only slightly to the heating value and yet, if removed from the gas, can be converted to a large number of oils, chemicals, etc., useful in making dyestuffs, pharmaceuticals, motor fuels, etc. On the contrary, although there are not exact figures in proof, it is the concensus of opinion of many who have studied the subject from actual experience, that what

may be termed the efficiency of the utilization of gas is not directly proportional to its calorific value. For many practical purposes—especially where high temperatures are required—a low B.t.u., say 300 to 350, is much more efficient per B.t.u. than a 600 B.t.u. gas. It is therefore to be desired that gas companies be permitted latitude in the type and quality of gas to be produced.* This will give them the opportunity of taking into consideration the local features affecting them. They can use the fuel that can be secured to best advantage and can apply the process of manufacture best adapted to the needs of the situation.

There are many types of manufactured gas at present and no doubt new apparatus soon will be perfected to produce new kinds, especially of low B.t.u. per cubic foot. Coal gas is made by various processes. The simple bench of six, eight or nine retorts, open at one end and hand-fired, is the type in general use in small city gas plants. The so-called horizontal or inclined "throughs" are similar, except that the retorts are open at both ends and machinery is used for charging coal and discharging coke. These are used in larger plants. Within the last decade benches of vertical retorts have been used successfully. They permit improved carbonizing results at low labor costs. Recently considerable experimenting has been done in applying steam to vertical retorts in the zone where the coal has been converted to coke. The result is the production of a variable amount of blue gas, which is of low calorific value and, when mixed with the coal gas, makes the output a larger quantity and of lower B.t.u. per cubic foot than is the coal gas alone. The possibilities of extending this process are great. English engineers have made good progress in this scheme of "steaming" and are producing generally a gas of from 400 to 450 B.t.u. per cubic foot, which, they claim, is at least as efficient in utilization as the higher B.t.u. gases. Coal gas is also made in coke ovens of various sizes and designs. Some of the large installations of ovens have coke as the principal product, and gas as one of the main by-products. This gas varies from 400 to 600 B.t.u. per cubic foot, depending upon the method of operation. Coke ovens are also built where gas is the chief product and coke, etc., the by-products.

* There is no doubt of the necessity for a lower B.t.u. gas standard in the United States. See also WHITWELL, *Gas Record*, **18** (1920), No. 7, 33.

Carbureted water gas is made very extensively, particularly in the eastern part of the United States. It came into popularity years ago when gas was used chiefly for lighting and oil was cheap. By this process a high candlepower gas is produced, but the present high price of oil has caused it to be a very costly process and practically prohibits the sale of carbureted water-gas at a price that large industrial uses require. The practical abandonment of the candlepower standard obviates the necessity for the use of oil to produce illuminating power and therefore the trend seems to be away from water-gas manufacture except for auxiliary service. If water gas is made without oil, the resultant so-called blue gas is of about 300 B.t.u. per cubic foot. There are numerous installations of this type of apparatus for purely industrial purposes, largely because of the high flame temperature of blue gas. The extensive use of large producer gas outfits in factories requiring gaseous fuel clearly shows that a high B.t.u. gas is not essential, because most of the producer gas machines turn out a gas of from 115 to 165 B.t.u. per cubic foot.

The mention of this diversity of gas-generating processes indicates the wide range of qualities and compositions of gas that may be produced and makes impressive the necessity for standards and regulations consistent with the needs of the situation. The answer seems to lie in establishing the British thermal unit—the B.t.u.—as a standard and selling gas in millions of B.t.u., instead of in thousands of cubic feet of some specified B.t.u. per cubic foot. A B.t.u. is of fixed value and therefore is an absolute standard. If a customer buys 1,000,000 B.t.u., he is not concerned with whether it is made up of 3,333 cu. ft. of 300 B.t.u. gas, 1,667 cu. ft. of 600 B.t.u. gas, or 1,000 cu. ft. of 1,000 B.t.u. gas. The producer thus is given the latitude of making gas by a process and of a type consistent with the materials available in his locality and selling it at a corresponding price. This procedure takes full advantage of the economics of the case, and therefore benefits both the consumer and the producer. It is to be expected that, in a given locality, the quality of gas furnished will not vary widely at frequent intervals. Appliances can easily be built to use efficiently gas of any specified B.t.u., which, by adjustment, will compensate for a considerable range of quality.

There is no longer a question regarding the efficient use of

manufactured gas for large industrial purposes, where the various conditions affecting its success are properly reckoned with. One needs only to survey some of the leading manufacturing cities to find many instances where millions of cubic feet of artificial gas—very largely coal gas—are sold daily, principally for metal treatment. There are numerous factories that are using from 1,000,000 to 3,000,000 cu. ft. per day each. These customers are not concerned with the B.t.u. per cubic foot of the gas supplied them. They are buying heat, properly applied, and are interested only in results consistent with the cost. The gas companies that have been successful in securing and holding users of large quantities of gas for industrial purposes specialize in rendering service in its full meaning. They provide a continuous supply of uniform quality gas and render the consulting and advisory service that causes the use of their gas to be more efficient and economical per B.t.u. than any other fuel. This large business has been secured by men of practical imagination who have solved the problems of the situation. The advantages of a gas fuel are manifold, some of them being cleanliness, convenience, quick response to the needs of varying temperatures, small waste due to accuracy and ease of control, etc. To secure this industrial business on a large scale, several conditions must be satisfied. Gas produced at a fairly low cost per B.t.u. must be available. A thorough study must be made of the process to which heat is to be applied covering the items of temperature desired, proper heat application, etc. Furnaces and burners must be designed, efficiently built and applied, taking into consideration the principles of regeneration, recuperation, ventilation, etc. These problems require men with a wide knowledge of the practical application of the theories of combustion, as well as a knowledge of the process to which the heat application is to be made. Men of the proper caliber are scarce, but surely a sufficient number of them will, as time passes, see the tremendous field for gas as industrial fuel and therefore prepare themselves to solve the problems that affect its broad exploitation. Serious mistakes have been made by trying merely to displace coal or oil in old appliances, with gas, without making alterations to or redesigning the appliances to suit gaseous fuel.

In considering selling gas in large quantities for industrial uses, the question of rates has a most important bearing. Careful study has been accorded this subject and consequently many

forms of rates have been devised and used with varying degrees of success. The customer who uses relatively small quantities of gas for lighting and domestic purposes naturally pays the highest rate because the cost of supplying him for those purposes is high on account of the expensive distribution system required for this class of business per unit of gas used. The industrial user, however, generally requires large volumes of gas over a considerable number of hours per day, and therefore places a more uniform demand upon the plant and distribution system and consequently justifies a lower rate. It is necessary to have protection for the investment required to supply users of large quantities of gas, so a rate for them should reckon with that feature. If a manufacturer installs his own apparatus for supplying heat, he must bear the cost of the investment at all times, even though he may need the maximum output of the apparatus only occasionally. Similarly, therefore, he should be satisfied to pay to a gas company the percentage of the fixed charges that is represented by the percentage that his demand is of the total. Due to the diversity factor on a distribution system supplying gas for lighting, domestic and industrial, the fixed charges that a given industrial customer would bear are practically certain to be considerably less than they would be on his own plant to serve the same purpose. In addition to the fixed charges on the investment, there are a few items of office and general clerical expense that are directly proportional to the number of users of gas, without regard for the volume consumed.

A rate that reckons with these features is a so-called *demand* or *readiness-to-serve* rate. An example of such a rate follows.

Customer's charge	$12.00 per year
Demand charge, per 100 cu. ft. of maximum hourly demand	36.00 per year
Consumption charge:	
First 25,000 per month	75 cts. per M.
25,000 to 100,000 per month	50 cts. per M.
100,000 to 1,000,000 per month	40 cts. per M.
Over 1,000,000 per month	35 cts. per M.

Payment of the customers' and demand charges is made in equal monthly installments.

If an industrial customer uses 2,000,000 cu. ft. a month, in a plant using gas at a uniform rate for 25 days a month and

10 hr. per day, the maximum hourly demand in this case is 8,000 cu. ft.

Rate (figured for 1 month):	
Customer's charge	$1.00
Demand charge (80 × $3.00)	240.00
Consumption charge:	
25 M. @ 0.75	18.75
75 M. @ 0.50	37.50
900 M. @ 0.40	360.00
1,000 M. @ 0.35	350.00
	$1,007.25

This makes the average rate slightly in excess of 50 cts. per M., as against a domestic rate in that community of $1 per M. It will be noted that, if the combustion were distributed evenly over more than 10 hr. a day, the maximum hourly demand would be less and the demand charge smaller. The reverse would be the case if the maximum hourly demand were greater. It is this feature that protects the gas company in the investment required to take care of the demand. Furthermore, a maximum hourly demand, once established, remains, on the theory that it was necessary to have equipment sufficient to care for that highest demand; and the investment, once made, requires an adequate return indefinitely. Such a rate protects the producer both as to investment and operating costs and is satisfactory to the consumer, particularly if his business causes the long hour use of gas on a good load factor.

In conclusion, it would seem justifiable to predict that the future of the artificial gas industry lies in the gasification of at least a large percentage of coal and thus supply by gas the heat that now is inefficiently derived from the direct burning of coal. To accomplish this, there must be carried on to a satisfactory final solution at least five big problems, previously mentioned in some detail.

1. Public utilities and their regulatory bodies must continue their efforts to arrive at a unit or standard of quality that will permit the producer of gas to use the process best suited to the materials available, let the gas be what it may, so that it can be sold in competition with other fuels at prices consistent with costs.

2. Rates must be made to protect the investment of the gas companies and give them a fair profit, and at the same time be

low enough to interest large manufacturing plants to use gas, instead of other fuels, for their heat requirements.

3. The good work that already has been done in developing efficient gas-making equipment must be advanced to the production of apparatus that is more flexible and that will utilize to the greatest efficiency all the components of coal; and by using each of the products of distillation to its greatest purpose, cause the production costs to be low.*

4. More men must be trained with a thorough knowledge of the practical application of the theories of combustion and heat application to all sorts of processes and requirements.

5. Continued progress and improvement must be made in the design of furnaces, burners, and all sorts of appliances suitable to use gas efficiently for practically any purpose.

Splendid progress has been made already in the investigation of these problems. The real goal of the artificial gas industry will have been reached when they all are solved satisfactorily.

* The manufacture of gas, although fundamentally a chemical problem, has been, and to some extent still is, directed on mechanical technologic lines. Healthy progress in the gas industry requires a better knowledge of the chemical fundamentals involved. See McBride, *Chem. Met. Eng.*, **23** (1920), 622.

CHAPTER XXI

HEAT APPLICATION

By

D. K. Bullens*

Industrial heating, as related to metallurgical processes, is concerned chiefly with the obtaining of a uniformly heated product of the best quality at the lowest cost. From both the metallurgical and economic standpoints the selection and use of fuel are the means to the end: the real problem of efficiently utilizing and applying heat to useful work is paramount.

Improvement must be sought through a clearer understanding, not only of the principles of heat generation, but also—and which is more important—of the principles governing the production of a uniformly heated product. This includes a more thorough study of furnace design from the standpoint of heat application, the handling of material to, within and from the furnaces, the layout of equipment with reference to efficiency of the process as a whole, and a better appreciation of the human element which controls the entire operation. These factors then must be linked together to obtain the result sought for—that is, a finished product, and which may be expressed as the cost of a unit of quantity of given quality.

Uniformly heated product involves a consideration of four fundamental factors:

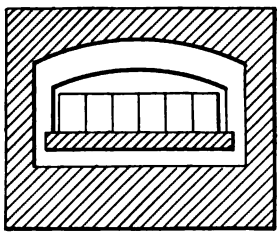
1. **Temperature**: *the degree of heat required in the product;*
2. **Time**: *the period required for saturating the mass to the required temperature;*
3. **Surface**: *the area exposed to the heat—which determines the rate of heating and influences the time of saturation and degree of uniformity;* and
4. **Mass**: *the unit body to be heated—which determines the time required for saturation, the rate of absorption and the manner of exposing to the heat.*

*President D. K. Bullens Co., consulting metallurgists, Philadelphia, Pa.

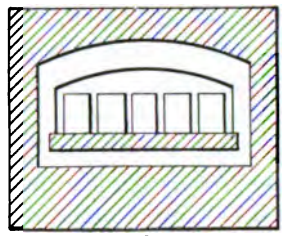
Uniformity of temperature of the heated product, aside from the degree of heat determined by definite metallurgical considerations, is a function of furnace design and operation indicated by temperature variation—not the temperature variation when the furnace chamber is empty or partially filled, but the temperature variation around the mass or pieces to be heated when the chamber is loaded to full working capacity. Heating a chamber uniformly and uniformly heating a charge within that chamber are two distinct operations. The former must accompany the latter, but the mere indication of the former, as may be shown by pyrometer records, does not by any means prove the existence of the latter. It does not follow that the temperature variation indicated in any two points in a chamber when empty will be the same as that indicated when the chamber is partially filled, or, more particularly, when it is filled to full normal working capacity. It is possible, therefore, to secure better results in finished product with one type of furnace having a distinctive method of applying heat to the charge over another without any apparent difference in the indicated variation in temperature at any given point or plane in the chamber when empty.

An annealing charge consisting of a number of small steel blocks is loaded in a furnace to its full capacity with the blocks placed closely together, as is illustrated by Fig. 366*a*. This arrangement is such that there is practically no opportunity for circulation of the heat around each block or unit body. The blocks in the center of the charge will require a longer period of time to attain the desired temperature than those towards the sides, which inevitably results in a difference in uniformity of the heated product. A better arrangement, whereby the heat may circulate around each individual piece, is shown in Fig. 366*b*, and illustrates the fact that the greater the surface exposed to the heat, the greater will be the degree of uniform heating and the less the time required for saturation.

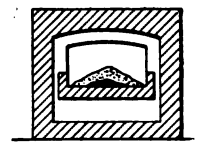
In the latter arrangement of the charge in an annealing operation it might be assumed that, when one block is saturated thoroughly, the balance are heated similarly. If the nature of the operation is changed to one of heating the blocks for forging into rings under a small steam hammer, making such change in the design of the furnace as would be necessitated by the higher temperature requirements, but without changing the number and arrangement of the pieces, the same condition would exist,



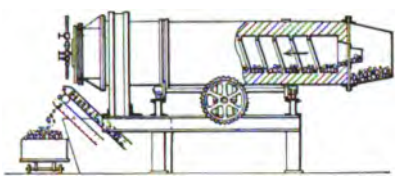
a



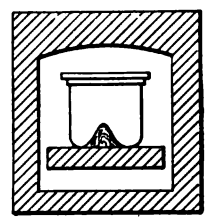
b



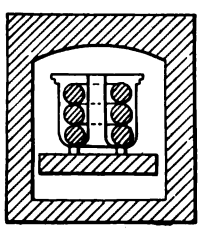
c



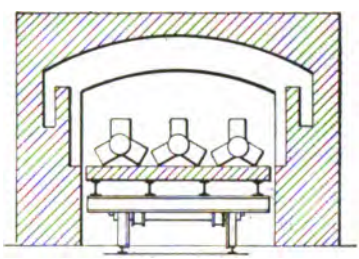
d



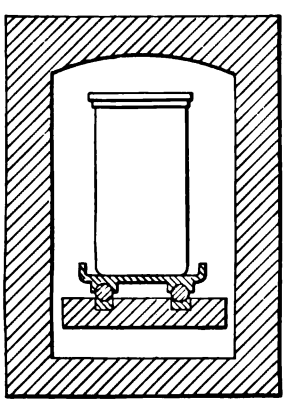
e



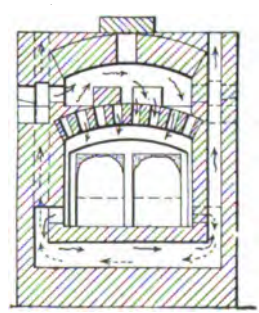
f



h



g



i

Fig. 366.

namely, that when one piece is hot the balance are hot. The forging operation, however, demands a definite time interval for the making of the ring, so that a considerable time will have elapsed before the last piece of steel is removed from the furnace. And if the first block is heated properly, as it must be, it automatically follows that the last block must be over-saturated and improperly heated, and a non-uniformity in finished product is the result. To obtain a more uniformly heated product for the purpose, the chamber being filled substantially with material all the time, as soon as one or two hot pieces are removed from the furnace, the same number of cold pieces should be put in to take their place. By this method of "one-in-and-one-out" a continuous cycle may be set up which will give each piece approximately the same period of exposure at the same temperature. In this way the hammerman does not have to wait for his stock to become heated, but always has hot material ready, thereby increasing production; at the same time, a constant output of uniformly heated stock is assured.

The difference between uniform chamber temperature and uniformly heated product is illustrated by Fig. 366c, in which it is assumed that the charge consists of very small pieces, such as bolts, washers, springs, etc., placed on the furnace floor. It is immaterial in this case whether the furnace is underfired or overfired, or how uniform the temperature in the chamber may be, because there always will be a tendency for a cool section to appear in the center, although it will be less with the underfired type. It is practically impossible to get a uniformly heated product under such conditions unless the charge is split up so as to permit free circulation of the hot gases through the mass. Unless each piece is exposed to the heat in the same manner and under the same conditions, there is apt to be a variation in the uniformity of heating between the pieces.

To heat uniformly a number of similar pieces it therefore is necessary to expose the same area of surface of each piece in the same manner, for the same length of time, at the same temperature. The usual lack of consideration of these points of identical area of exposure and time of saturation accounts for the variations that so often occur in the finished product without any change in the indicated temperature.

Instead of heating such small pieces in the manner indicated in Fig. 366c, it is better practice to employ an automatic type of

furnace like that of Fig. 366*d*. With a furnace of this type the entire surface of each piece is exposed to the action of the heat in the same manner for the same time and each piece practically is heated separately.

The uniform heat treatment of large quantities of pieces of similar shape and size requires not only a uniformly heated product but also a uniformly cooled product. The former is the preparation for the latter, and the failure of one part of the procedure means a total loss of the other as well. The single-end, stationary-hearth annealing furnace used for heating the blocks previously mentioned serves equally well for the cooling operation, inasmuch as furnace cooling is demanded by the metallurgical requirements of annealing. But change this last condition, assume that the pieces are dieblocks with the impressions sunk and are to be heated for quenching, and the heat application problem is changed entirely. The above type of furnace might be satisfactory for bringing the blocks up to final heat through a slow soaking process without subjecting the corners—the crux of the dieblock problem—to the final temperature any longer than absolutely necessary; but the time element involved, the high degree of care and attention necessary, and the great amount of handling apparatus required by the quenching operation would react against proper and uniform cooling with a number of pieces involved, as in the case in question.

Under such conditions it would be better practice to use a furnace of the continuous type. The dieblocks could be placed on carriages at the low-temperature end of the furnace, conveyed through the furnace at a gradually increasing temperature, and reach the discharge end heated to the desired temperature with the proper period of saturation. Each block in turn then could be cooled in a suitable manner under identical conditions of temperature and time, the factors of surface and mass likewise being constant. A hot block is removed from the furnace and a cold one is charged in; a hardened block is removed from the quenching tank and a hot block put in. In this way a uniformly heated product is linked with a uniformly cooled product, to produce a finished product of uniform quality. It illustrates the principle that, to heat treat uniformly a number of similar pieces, it is necessary to expose the same area of surface of each piece in the same manner, for the same length of time, at the same temperature, *not only in heating, but also in cooling.*

Similar examples might be given, such as rifle barrels, shells, automobile axles, crank-shafts, etc., as well as the application of the rotary furnace of Fig. 366*d* to quenching. In each case the principle of "one-in-and-one-out" is adapted to mechanical handling. It emphasizes the fact that it is a physical impossibility to maintain a uniform temperature in any furnace regardless of the manner of heating, or of utilizing or applying the heat, unless there is a uniform input and output of material.

In the small forge furnace example previously given, the "one-in-and-one-out" was applied to a single-end, stationary-hearth furnace in order to approach the continuous cycle with a furnace which it was inadvisable to make automatic. An increase in the size of the hammer and of the size of the pieces to be forged would demand a corresponding increase in the size of the chamber; so that, if this line of reasoning were to be followed out, it would be assumed that a single-chamber furnace of considerable size would be required to heat the charge for a large hammer or press. Such reasoning would be faulty, however, in that it does not consider all the factors associated with the relation of furnace, heated product and machine. Plant layout and operating efficiency would be satisfied better by having a plurality of chamber or furnace units. By the time a hot ingot or forging in one unit had been worked and it or another piece recharged, a piece in another unit would be hot, and so on. In a method such as this, hot steel, properly heated, always would be ready and the principle of "one-in-and-one-out" would still apply, although a plurality of units or chambers would be involved. This is advantageous not only from the standpoint of producing a continuous supply of uniformly heated pieces, but also in the matter of repairs, because one unit could be repaired without affecting the operation of the other units or the hammer.

In a forge operation involving a plurality of units the entire charge of several pieces in any one furnace cannot be discharged properly at substantially the same time because there is the forging period element to be considered. But change the nature of the problem to a heat treatment operation, such as drawing or tempering, involving a plurality of units, and it would be considered good practice to discharge the entire load in the furnace at the same time. In this latter case there is not the element of machine time involved, so that, when one piece is heated properly, the whole charge is hot and may be removed. It illustrates

the fact that the heat-application proposition must be considered in the relation which it bears to subsequent operations and that the distinctive unit of the "one-in-and-one-out" principle may be determined as either an individual piece in the charge or as the charge as a whole, depending upon whether a further operation, requiring a definite period of time for its consummation, is involved.

Wire commonly is annealed in coils placed in pots, as illustrated by Fig. 366*e*. But no matter how uniform the temperature may be in the chamber there always will be a tendency for a cold zone at the bottom of the pot, as is represented by the shaded portion in the drawing. Raising the pot from the furnace floor will reduce this effect somewhat, inasmuch as it provides for circulation of the hot gases under the pot. Greater uniformity of heated product again may be obtained by using a construction of pot illustrated in Fig. 366*f*. In this instance the heat is applied to the center of the pot as well as the outside, and to the bottom as well as the top, thus exposing a greater area of surface to the heat. Greater efficiency in handling heavy and cumbersome pots might lead to the use of a movable car-and-ball type furnace outlined in Fig. 366*g*. In this problem the advisability of continuous method should also be considered, since it is desirable to have each pot of wire leave the furnace at the same temperature after having had the same period of saturation in the furnace.

The pot method of annealing wire might be commercially acceptable for material having a wide temperature range and the heat application considered as applying to coils of wire composing the mass and not to a case in which the unit is one of strands. It is evident, however, that the strands at the inside and outside of a coil will tend to have different saturation periods, as will also the strands in the different coils in a single pot, the degree of difference depending upon the size of the coil, the height of the pot, and the design of the furnace. With high-grade wire, such as resistance wire, in which the permissible temperature variation is much less, heating in coils would have the tendency to be unsatisfactory and it would be desirable to employ a furnace in which the wire is passed through in strands. With equipment of this type the operation would be continuous, the wire would be brought up to temperature gradually, instead of being introduced into an atmosphere at the temperature supposed to finish the work, and the period of saturation would be made uniform, as well

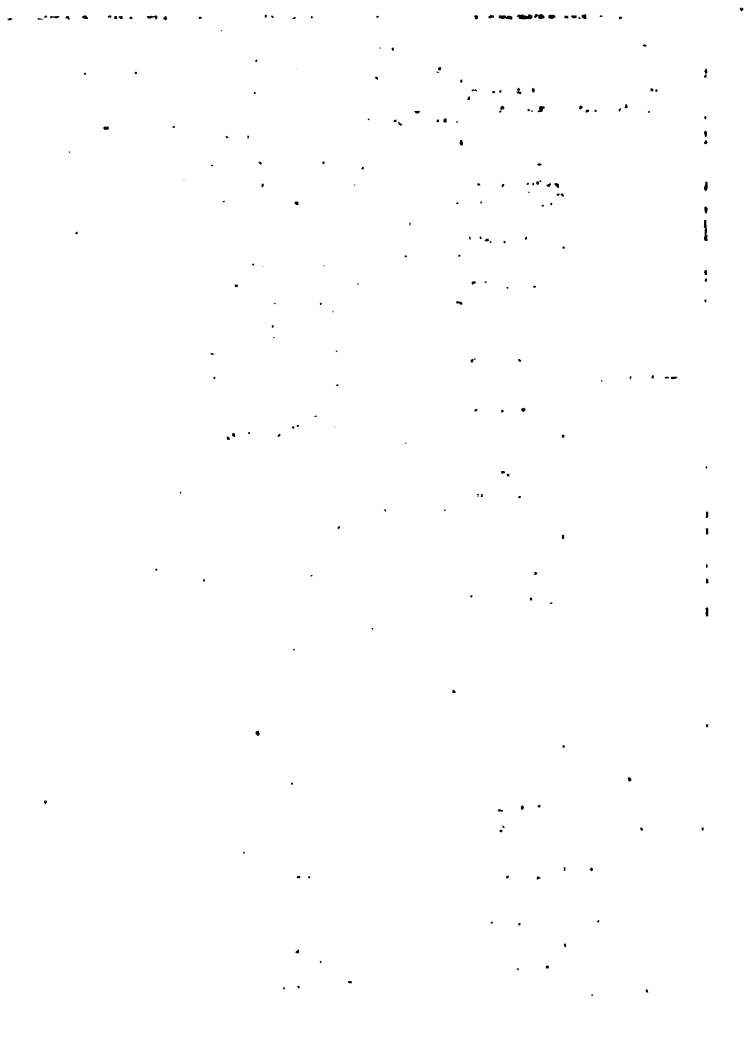
as passing the strands of wire through tubes or other devices to protect the metal from oxidation. In this case the nature of the mass (the unit being one of a strand and not of a coil of wire) and character of the finished product would determine the selection of furnace type and fuel.

The importance of the problem of selecting the right type of furnace from the standpoint of heat application and the relation of surface and mass may be illustrated also by such examples as the roasting of sulphide ores, or the drying of sand and calcining of cement. Sulphide concentrates placed in a pile or thick layer on a furnace hearth could be heated for hours, and yet if the mass were not broken up by rabbling and the surface of each individual particle of sulphide exposed to the oxidizing process an incomplete roasting would result. Similarly, a mass of sand or cement placed upon the hearth of a furnace never would become heated uniformly in the practical sense, and rotary furnaces must be used to break up the mass and expose the maximum surface. And yet all this is independent of the usual factors incident to the generation and utilization of heat, such as combustion, burners, vents, flues, recuperation, fuel economy, etc.

These examples illustrate the point that, as the mass increases and the size of the unit piece decreases, there comes the necessity for a furnace type and method of handling making possible a breaking up of the mass and an increase of exposed surface in order that each piece may be heated alike. When this is done properly there is economy in fuel as well as uniformity of product.

The character of the charge in its relation to handling efficiency may determine the furnace type to be used regardless of thermal efficiency or heat utilization. A steel foundry producing a variety of large castings of considerable size and weight, or a press shop with long and heavy crankshaft forgings, requiring annealing, might logically determine upon a car-type annealing furnace, such as is illustrated in Fig. 366*h*, as the proper solution of its problem. In such cases the use of furnaces with movable car bottoms would be permissible from the standpoint of handling, and mechanical efficiency thus take precedence over thermal efficiency.

In the above illustration the character of the charge is such that the unit mass cannot be reduced. But if the charge consists of a pack of steel plates, making a mass of considerable size, such as is illustrated in Fig. 366*i*, it would be better practice to use a



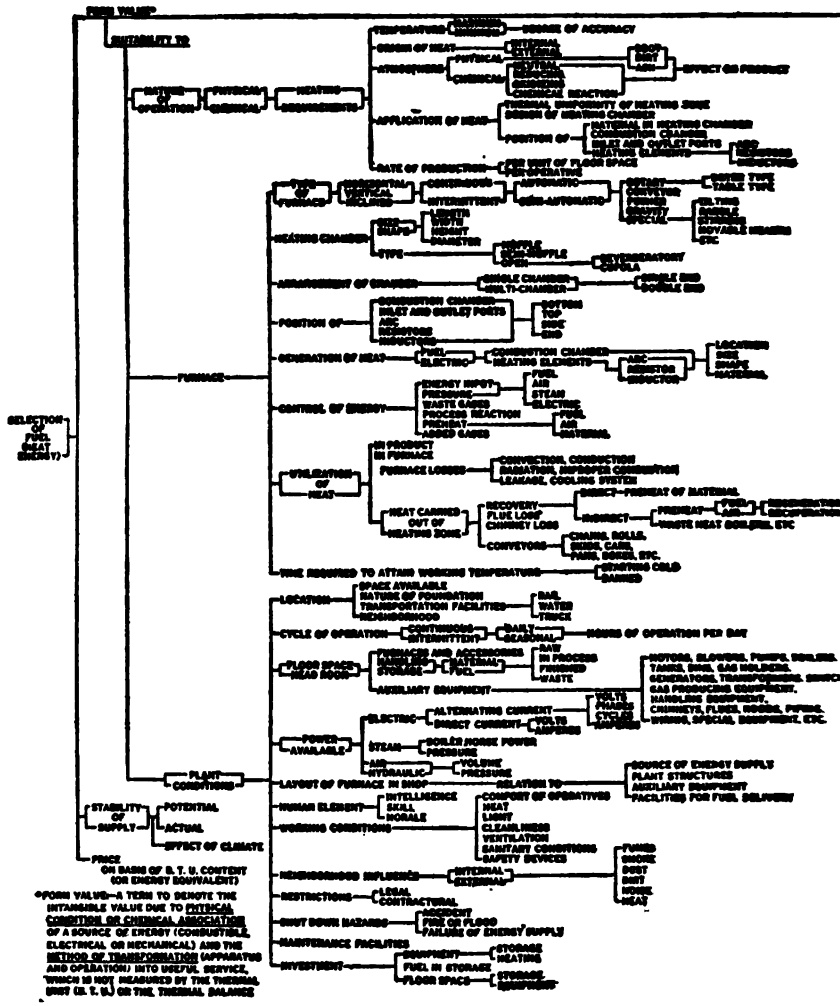
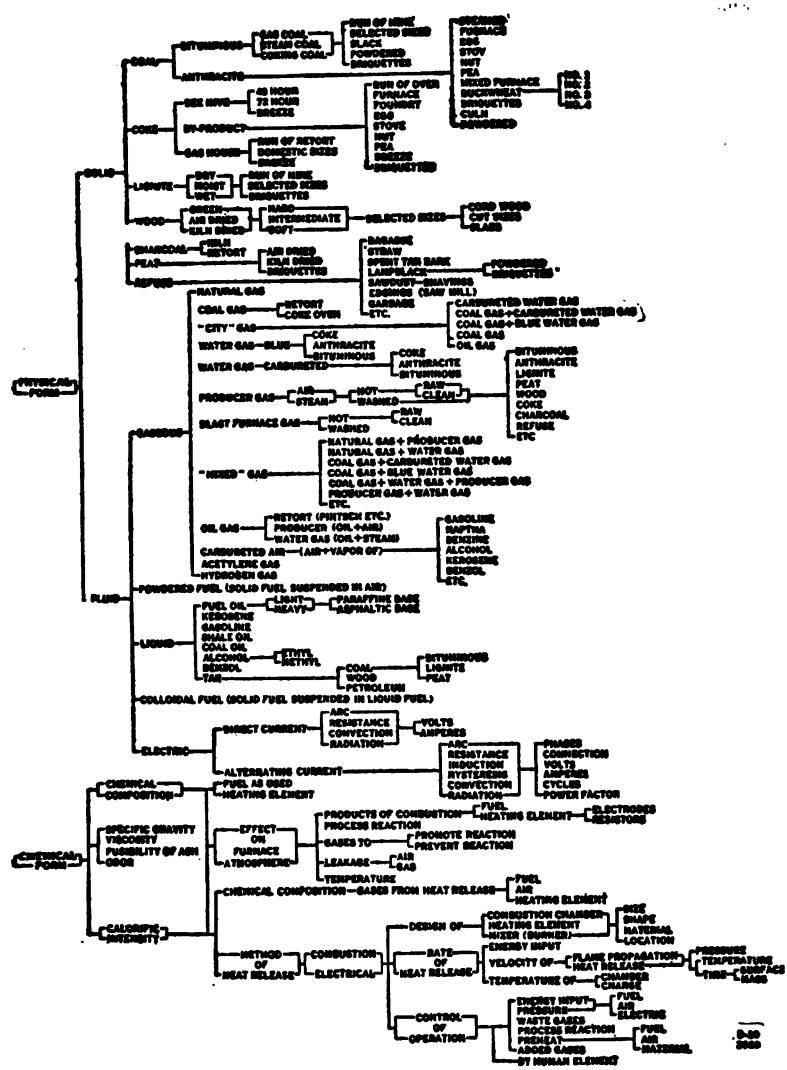


Fig. 367.—Factors governing the selection of fuel (heat energy) for industrial heating o



tions. *(Published through the courtesy of the W. S. Rockwell Company, New York.)*

(Facing page 1116.)

furnace design which would entail a breaking up of the mass into smaller units, exposing more surface, and therefore obtaining not only better heat utilization but also better heat application.

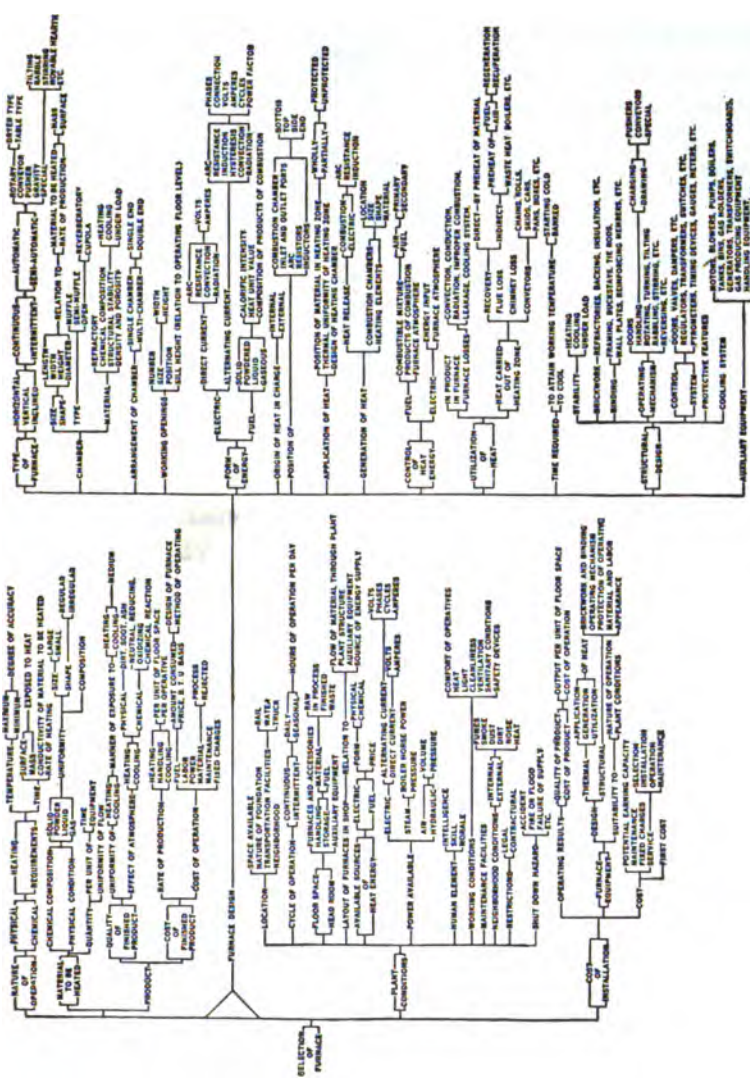


FIG. 368.—Factors governing the selection of furnaces for industrial heating operations. (*Published through the courtesy of the W. S. Rockwell Company, New York.*)

Metallurgical considerations oftentimes may be the deciding factor in the selection of furnace type. Long tubes for heavy cannon and naval rifles might properly be annealed or tempered

in a horizontal position in a car-and-ball type, a car-bottom, or even in a pit furnace. But if these long tubes had to be quenched for hardening, metallurgical requirements would demand that

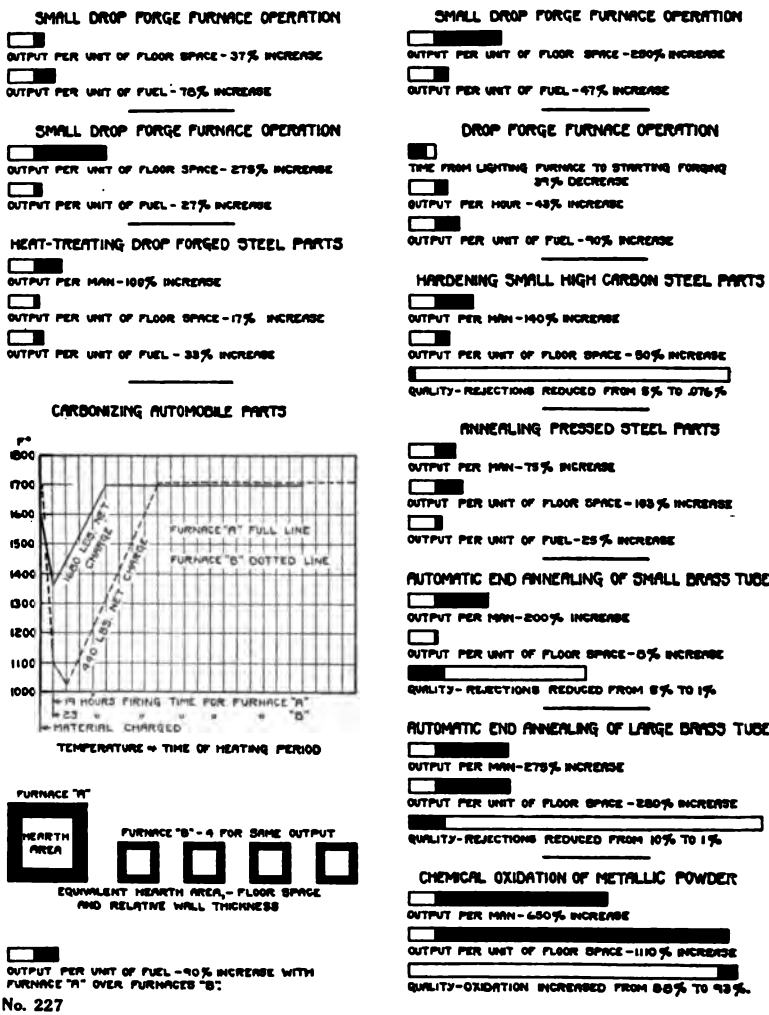


FIG. 369.—Influence of furnace design on cost of production. (*Published through the courtesy of the W. S. Rockwell Company, New York.*)

they should be heated and quenched in a vertical position in order to avoid bending, warping, etc., and a high, vertical, cylindrical furnace type would be the choice. In selecting a

furnace design, it is necessary to consider the metallurgical requirements and the mechanical features incident to handling the material to be heated, in addition to the thermal efficiency of the furnace.

Many of the irregularities in heating for forging are common to the mill operations of heating for rolling, and a great deal of the difficulty due to lack of uniformity could be eliminated by a better control of the heating in the mill when the ingots or billets are rolled, and in the forge shop when the stock is formed into shape. The basic factors of temperature, time, surface and mass are applicable to any heating operation, whether it is rolling, forging or any of the various branches of heat-treatment work. The lack of consideration of these points in general forging practice has retarded greatly the advance of the art towards better heat application and consequently has affected adversely the quality of the finished product. Better furnace design and economies in heat utilization and fuel conservation cannot be realized until the weak links in forging practice are corrected.

Slow, soft, soaking heats, affording the steel plenty of time to heat up, are more desirable than the quick, higher heats. The idea should be to maintain the temperature of the furnace as near as possible to that actually required to soften the steel to the extent necessary for its proper shaping in relation to the capacity of the hammer or press, and to give it plenty of time in the furnace to soak thoroughly at this temperature without overheating or oxidizing the outside. If the proper temperature has been used, the steel thoroughly saturated, and the fire soft and a little high in carbon to minimize oxidation, the men will find that the steel actually will forge more easily and a greater production be obtained than under the old method of quick wash or surface heats. With proper saturation it also will be found that much lower temperatures may be used and that working conditions will be made more bearable. Such a practice not only is better for the man, but also is much better for the steel from the standpoint of quality. It has the added advantage of being less costly, because it is almost impossible to effect these improvements without at the same time decreasing the operating cost.

General heating practice is such that there is little or no thought given to the improvements which can be brought about by the intelligent use of heat; and many manufacturers appear to be satisfied to conduct their heating operations in any kind

of a furnace in which heat can be made, with any kind of an operator to run it, provided he will keep it going by maintaining the supply of fuel and keeping an eye on the pyrometer, on the assumption that by such a procedure he is doing all that is necessary. It invariably works out that the operator in effect is doing nothing more than manufacture pyrometer records, instead of properly heating his metal. He will watch the pyrometer and turn a valve so as to at least maintain an appearance of doing work properly, but observations as to the condition of the metal, in order to determine if it is being oxidized and if the the heat is being applied alike to all pieces, are matters that apparently receive little of his attention.

The pyrometer has been of inestimable value in affording a means to check temperature, but, and aside from the correlation of results, its efficiency ends largely with that indication. The uniformity of heated product, however, depends upon the manner of applying the heat, which, with the method and cost of operation, is primarily a function of furnace design and furnace operation. It is possible to indicate a uniform temperature and yet not produce a uniformly heated product; and unless the heat is applied uniformly to the stock at the temperature indicated, then a uniform pyrometer reading is misleading and inconclusive. Thus an elaborate pyrometer system, with means for signaling variations in temperature and of recording these variations, is not all that is necessary to control accurate heating. In fact, such a signal system is useless unless the temperature is checked with the time, mass and surface of exposure. The pyrometer and the clock must go together, and the judgment of the furnace operator must go with both.

Again, it is common practice to install an expensive furnace, costing thousands of dollars, and employ a cheap, inefficient man to run it, notwithstanding the fact that it is the man who controls the output and cost of operating the furnace. When the relationship of the human element to the result is of less importance, as, for instance, with a machine press, as it surely is when compared with a furnace, then there will be manifested the false economy effected by the employment of unskilled, inefficient furnace operators. In the final analysis the furnace is nothing more than a tool in the hands of the operator, and the value of the human element depends upon the amount of skill that must be exercised in the use of a tool, whether it is a hammer,

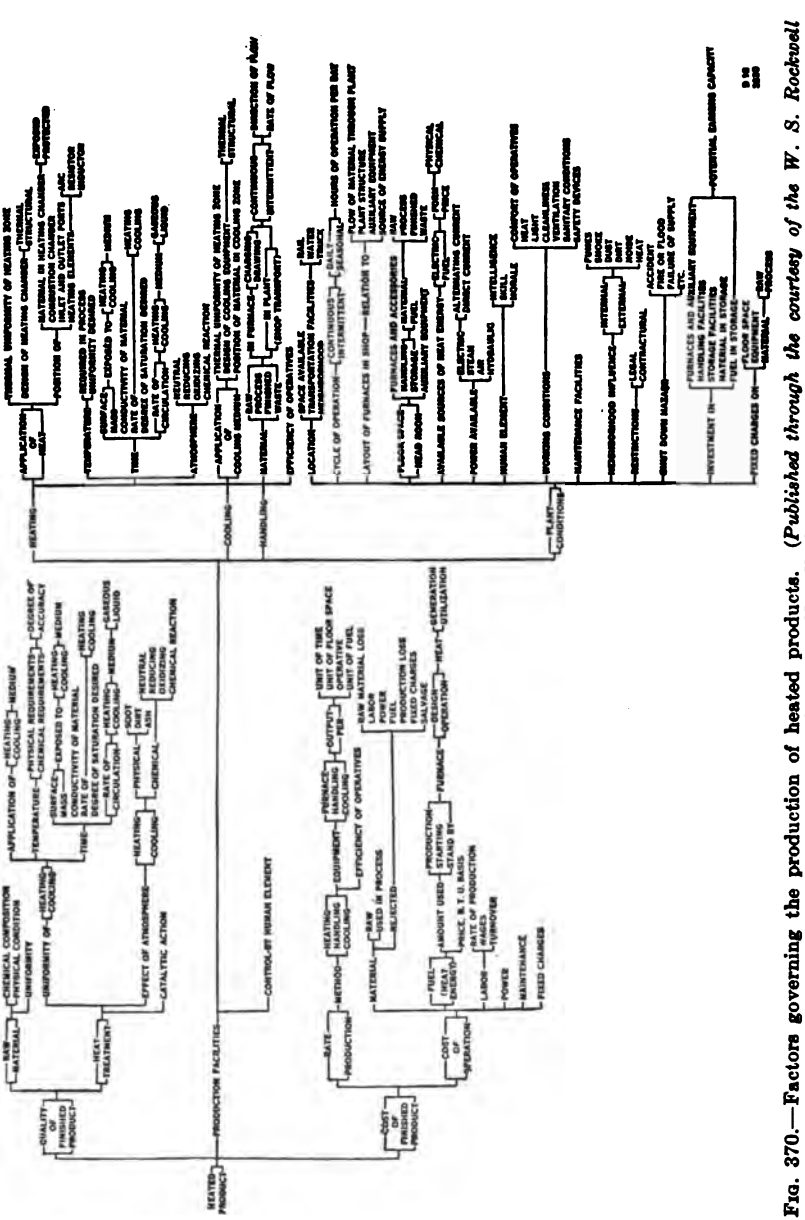


FIG. 370.—Factors governing the production of heated products. (*Published through the courtesy of the W. S. Rockwell Company, New York.*)

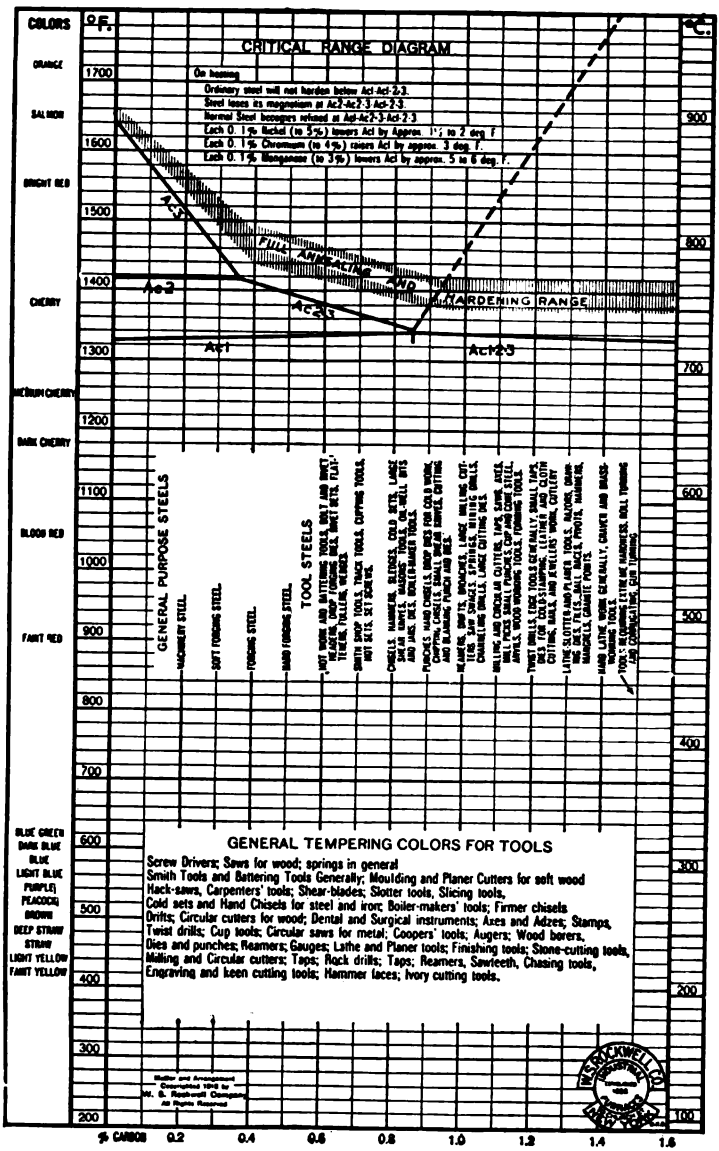


FIG. 371.—Steel heat-treatment chart. (*Published through the courtesy of the W. S. Rockwell Company, New York.*)

a chisel, a press or a furnace. There are many cases when it is permissible to employ unskilled labor in connection with a machine, where the operation is more or less automatic and the operator is required to do nothing more than start or stop the movement and feed material. Such a practice, however, is foolhardy with a furnace, because of the paramount importance of the human element in the operation. It is a waste of money to install efficient types of furnaces, which are necessarily expensive, without providing for intelligent supervision over the operation in the form of at least one efficient man who can either operate it himself or direct its operation by others. The practice of employing at least one skilled man for such a purpose is gaining headway and undoubtedly will continue to do so, as his labor is usually more than paid for by the savings effected in the cost of the operation, to say nothing of the betterment of the product.

The human element in heating operations is important and needs attention and improvement. The best men available are none too good for such important work. They should be afforded every possible facility for comfort, handling of material and good furnaces which will make possible absolute control of every step of the operation, whether it is the making of the fire, the control of the atmosphere, the flow of spent gases or the application of the heat to the stock. It is a combination of the man, the furnace and the steel that determines the result, and not any one or two of them.

In this chapter it has been the endeavor to present a new, but nevertheless necessary, phase of metallurgical work, that of heat application. A uniformly heated product, a product of better quality at lower cost, has been regarded as the end sought for in industrial heating, and the fundamental factors of temperature, time, surface and mass have been discussed with that in mind. The need for a fuller consideration of methods of handling material, the relation of the furnace to the process as a whole and the importance of the human element have been indicated. And it is a clear understanding and proper correlation of these principles of applying heat, after it is generated, to useful work which form the basis for the determination of furnace types.

CHAPTER XXII

THE RELATIVE THERMAL ECONOMY OF ELECTRIC AND FUEL-FIRED FURNACES

By

E. F. Collins*

It is well known that the thermal efficiency of a fuel-fired furnace decreases rapidly with increasing working temperature. This decrease is due primarily to the fact that the air required for combustion must be heated to the temperature of the furnace gases, the heat necessary to raise the air to this temperature usually being lost in the products of combustion as they escape. A secondary cause is the heat lost to the room from the walls of the furnace, which, for convenience, is called the radiation.

It is not possible to state with exactness the efficiency which may be realized in a furnace unless all the working conditions are known, *as there are many factors which influence the amount of heat, its distribution and ultimate useful utilization.* For instance, a part of the heat leaving the furnace may be recovered by preheating the fuel and incoming air, or by heating water or other materials for incidental uses; or in some cases the furnace may be constructed on the compensating or counter-flow principle, when a considerable amount of heat may be returned to the incoming charge.

These possibilities are, in general, only in relatively large furnaces or installations, in which the plant and character of work admit of the utilization of the waste heat. The ordinary furnace and average plant operating conditions do not offer such opportunities for conservation of heat.

This Chapter deals with none of these compensating or regenerative schemes. The comparative thermal efficiency is therefore approximated by simple calculations for simple furnaces; since practically all the theoretical heat represented by the tempera-

* Consulting Engineer, Industrial Heating Devices, General Electric Company, Schenectady, N. Y.

ture of the flue gases is lost, and no approximations are necessary for complicated auxiliaries.

Data showing the theoretical losses in flue gases for various fuels at various temperatures, have been reported by others; but it is thought that it may be of interest to present these data in the form of tables and charts, so as to make them available for ready reference in comparing the various fuels with electric heat, from the standpoint of thermal efficiency, as well as the cost per heat unit when used for the same work and in furnaces of identical thermal loss from radiation.

The applications of electric heating are being extended very rapidly; and if the cost of electricity decreases as in the past, the point soon may be reached where the comparative cost, even on a B.t.u. basis, will not be unfavorable to electric heat. As a matter of fact, such a comparison at present prices is not unfavorable to electric heat at the higher temperatures, as will be shown presently.

Table CXXIV has been compiled to show the heat losses and the cost per 100,000 B.t.u. actually utilized in useful work for various fuels, including electricity, at temperatures of 400°F., 1,600°F., 2,300°F. and 2,800°F.—temperatures usually required for baking, heat treating, forging and melting, respectively.

The values of flue losses have been calculated for 100 per cent air, or the theoretical air required for perfect combustion, and also for 150 per cent air, or 50 per cent in excess of combustion requirements, which represents more nearly the average conditions. Radiation losses of 15,000, 20,000, 30,000 and 40,000 B.t.u., respectively, have been assumed arbitrarily for the four temperatures above mentioned, and the same radiation loss has been assumed for all fuels, so that they thus are compared on the same basis; or it may be assumed that all the fuels are burned in the same furnace with perfect combustion and also with air in excess of 50 per cent. Average calorific values of the fuels are stated, and their costs per ton or per gallon, etc., are in round figures for easy calculations and so that any other costs per ton or per gallon may be applied readily.

It should be borne in mind that the thermal efficiency shown in the tables is the theoretical maximum for the conditions stated, and complete combustion is assumed in all cases. The values actually realized in practice will represent a more or less lower efficiency than the tables and curves presented. Note that

TABLE CXXIV.—DATA SHOWING RELATIVE THERMAL EFFICIENCY AND COST OF ELECTRICITY AND VARIOUS FUELS

Source of heat	Per cent of air for perfect combustion, air at 10°F.	Calorific value of fuel or power, B.t.u.	Temperature of furnace, °F.	Rate paid for fuel or power	Cost per 100,000 B.t.u.	Losses		Total B.t.u. required for 100,000 B.t.u., effective	Thermal efficiency of furnace	Cost per 100,000 B.t.u., effective
						Per cent of available B.t.u. lost in flue gases	Assumed radiation, B.t.u.			
Coke	100	13,000 per lb.	400	$10.00 per t.	$0.0385	7.5	15,000	124,000	80.6	$0.0477
Coke	150	13,000 per lb.	400	10.00 per t.	0.0385	10.5	15,000	128,500	77.8	0.0493
Coke	100	13,000 per lb.	1,600	10.00 per t.	0.0385	32.5	20,000	178,000	56.2	0.0685
Coke	150	13,000 per lb.	1,600	10.00 per t.	0.0385	48.5	20,000	233,000	43.0	0.0898
Coke	100	13,000 per lb.	2,300	10.00 per t.	0.0385	47.5	30,000	248,000	40.3	0.0955
Coke	150	13,000 per lb.	2,300	10.00 per t.	0.0385	71.0	30,000	448,000	22.3	0.1730
Coke	100	13,000 per lb.	2,800	10.00 per t.	0.0385	57.5	40,000	330,000	30.3	0.1270
Coke	150	13,000 per lb.	2,800	10.00 per t.	0.0385	87.0	40,000	1,071,000	9.3	0.415
Electricity	...	3,415 per k.w.h.	400	1¢ per k.w.h.	$0.293	0.0	15,000	115,000	87.0	$0.337
Electricity	...	3,415 per k.w.h.	1,600	1¢ per k.w.h.	0.293	0.0	20,000	120,000	83.5	0.352
Electricity	...	3,415 per k.w.h.	2,300	1¢ per k.w.h.	0.293	0.0	30,000	130,000	77.0	0.380
Electricity	...	3,415 per k.w.h.	2,800	1¢ per k.w.h.	0.293	0.0	40,000	140,000	71.5	0.410
City gas	100	590 per cu. ft.	400	$1.00 per m.	$0.17	15.0	15,000	135,000	74.0	$0.230
City gas	150	590 per cu. ft.	400	1.00 per m.	0.17	17.5	15,000	139,000	72.0	0.236
City gas	100	590 per cu. ft.	1,600	1.00 per m.	0.17	44.0	20,000	214,000	46.7	0.364
City gas	150	590 per cu. ft.	1,600	1.00 per m.	0.17	51.0	20,000	245,000	40.8	0.416
City gas	100	590 per cu. ft.	2,300	1.00 per m.	0.17	60.0	30,000	325,000	30.8	0.552
City gas	150	590 per cu. ft.	2,300	1.00 per m.	0.17	70.0	30,000	433,000	23.1	0.736
City gas	100	590 per cu. ft.	2,800	1.00 per m.	0.17	72.5	40,000	509,000	19.7	0.865
City gas	150	590 per cu. ft.	2,800	1.00 per m.	0.17	85.0	40,000	933,000	10.7	1.585
Fuel oil	100	19,000 per lb.	400	10¢ per gal.	$0.0748	14.0	15,000	134,000	74.6	$0.100
Fuel oil	150	19,000 per lb.	400	10¢ per gal.	0.0748	17.5	15,000	139,000	72.0	0.104
Fuel oil	100	19,000 per lb.	1,600	10¢ per gal.	0.0748	40.0	20,000	200,000	50.0	0.150
Fuel oil	150	19,000 per lb.	1,600	10¢ per gal.	0.0748	55.0	20,000	267,000	37.5	0.200
Fuel oil	100	19,000 per lb.	2,300	10¢ per gal.	0.0748	56.0	30,000	296,000	33.8	0.222
Fuel oil	150	19,000 per lb.	2,300	10¢ per gal.	0.0748	77.5	30,000	577,000	17.3	0.432
Fuel oil	100	19,000 per lb.	2,800	10¢ per gal.	0.0748	67.5	40,000	430,000	23.3	0.322
Fuel oil	150	19,000 per lb.	2,800	10¢ per gal.	0.0748	94.0	40,000	2,330,000	4.3	1.745

Anthracite coal	100	12,000 per lb.	400	$10.00 per t.	$0.0425	9.0	15,000	126,500	79.0	$0.0548
Anthracite coal	150	12,000 per lb.	400	10.00 per t.	0.0425	12.5	15,000	131,500	76.0	0.0570
Anthracite coal	100	12,000 per lb.	1,600	10.00 per t.	0.0425	35.0	20,000	185,000	54.0	0.0805
Anthracite coal	150	12,000 per lb.	1,600	10.00 per t.	0.0425	50.0	20,000	240,000	41.7	0.1020
Anthracite coal	100	12,000 per lb.	2,300	10.00 per t.	0.0425	50.0	30,000	260,000	38.5	0.1105
Anthracite coal	150	12,000 per lb.	2,300	10.00 per t.	0.0425	72.5	30,000	473,000	21.1	0.2010
Anthracite coal	100	12,000 per lb.	2,800	10.00 per t.	0.0425	60.0	40,000	350,000	28.6	0.1490
Anthracite coal	150	12,000 per lb.	2,800	10.00 per t.	0.0425	87.5	40,000	1,120,000	8.93	0.476
Bituminous coal	100	12,550 per lb.	400	$ 5.00 per t.	$0.020	11.0	15,000	129,000	77.5	$0.0258
Bituminous coal	150	12,550 per lb.	400	5.00 per t.	0.020	15.0	15,000	135,000	74.0	0.0270
Bituminous coal	100	12,550 per lb.	1,600	5.00 per t.	0.020	38.5	20,000	195,000	51.3	0.0390
Bituminous coal	150	12,550 per lb.	1,600	5.00 per t.	0.020	52.5	20,000	253,000	39.5	0.0506
Bituminous coal	100	12,550 per lb.	2,300	5.00 per t.	0.020	55.0	30,000	289,000	34.6	0.0578
Bituminous coal	150	12,550 per lb.	2,300	5.00 per t.	0.020	75.0	30,000	520,000	19.2	0.1040
Bituminous coal	100	12,550 per lb.	2,800	5.00 per t.	0.020	65.0	40,000	400,000	25.0	0.0880
Bituminous coal	150	12,550 per lb.	2,800	5.00 per t.	0.020	90.0	40,000	1,400,000	7.15	0.2800
Natural gas	100	1,100 per cu. ft.	400	30¢ per m.	$0.0273	16.2	15,000	137,000	73.0	$0.0374
Natural gas	150	1,100 per cu. ft.	400	30¢ per m.	0.0273	20.0	15,000	144,000	69.5	0.0393
Natural gas	100	1,100 per cu. ft.	1,600	30¢ per m.	0.0273	44.0	20,000	214,000	46.7	0.0585
Natural gas	150	1,100 per cu. ft.	1,600	30¢ per m.	0.0273	59.0	20,000	292,000	34.2	0.0797
Natural gas	100	1,100 per cu. ft.	2,300	30¢ per m.	0.0273	60.0	30,000	325,000	30.8	0.0886
Natural gas	150	1,100 per cu. ft.	2,300	30¢ per m.	0.0273	81.0	30,000	685,000	14.6	0.1870
Natural gas	100	1,100 per cu. ft.	2,800	30¢ per m.	0.0273	72.5	40,000	510,000	19.6	0.1390
Natural gas	150	1,100 per cu. ft.	2,800	30¢ per m.	0.0273	97.5	40,000	5,600,000	1.8	1.530

in the case of electricity, which is perfectly converted into heat, only a radiation loss occurs; and escaping hot gases at furnace temperatures do not exist, as in fuel-fired furnaces.

Figure 372 shows the heat available from Table CXXIV, arranged in the form of charts, and illustrates in a rather striking manner the relative efficiency of the various fuels at the four

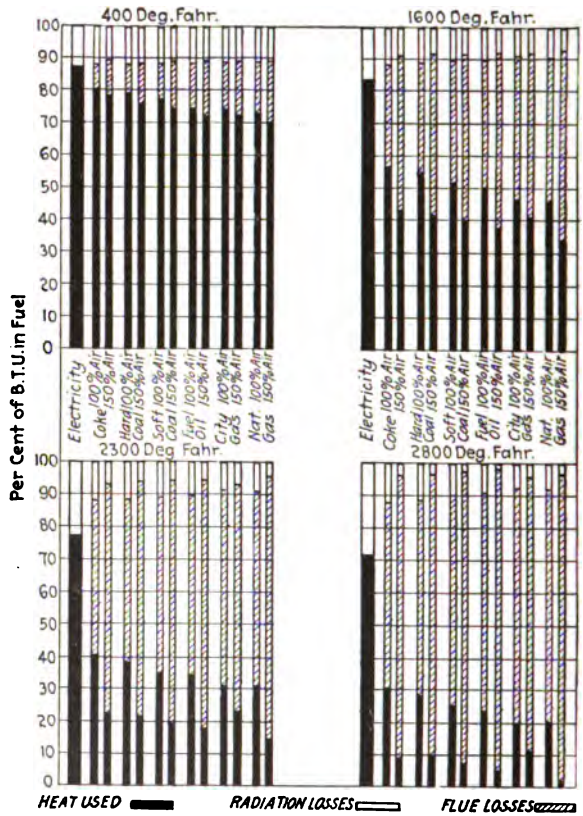


FIG. 372.—Chart showing relative thermal efficiency and relative proportions of losses for various fuels.

temperatures chosen, as well as the relative proportions of the losses. The rapid decrease of efficiency with rising temperature and increased air supply is at once apparent in the case of fuel-fired furnaces. Figure 373 illustrates the relative cost of fuels at various temperatures, with 100 per cent air supply, plotted as curves, and Fig. 374 shows the corresponding cost for 150 per cent air supply, the values having been plotted from the last

column of Table CXXIV. Figure 372 shows the high ratio of heat utilized to heat units supplied by electricity, as compared

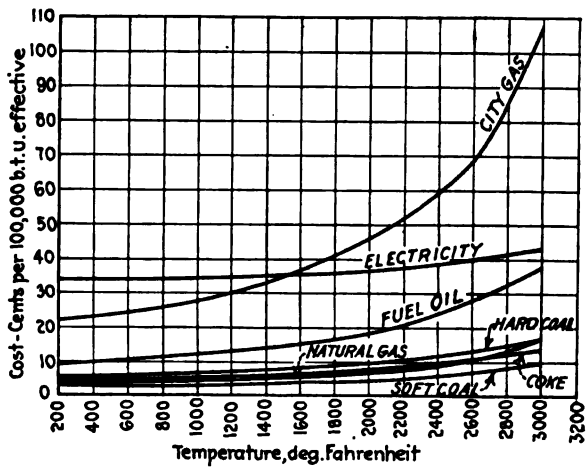


FIG. 373.— Curves showing the relative cost of fuels at various temperatures for 100 per cent air supply. Values plotted from Table I.

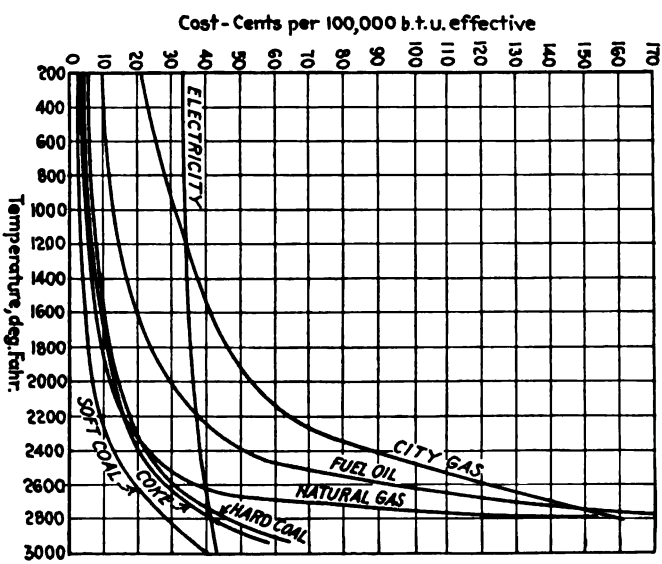


FIG. 374.—Curves showing the relative cost of fuels at various temperatures for 150 per cent air supply. Values plotted from Table I.

with combustible fuels, while Fig. 373 and Fig. 374 present its comparative cost per 100,000 B.t.u. For fuel costs other than

those chosen, curves may be plotted by multiplying the values in the last column of the table by the ratio to actual fuel cost. For instance, for oil at 14 cts. per gallon, or electricity at 1.25 cts. per kilowatt-hour, multiply the values in the last column of the table by 1.4 or 1.25, and plot a new curve.

The foregoing is, of course, on a strictly B.t.u. basis, without regard to the expense of handling or storing fuels, or to the cost of repairs, convenience of manipulations, etc. It has been demonstrated that, even at a higher cost per heat unit, electric heat, in many cases, is actually cheaper, and at the same time offers an opportunity to increase output and improve the quality of the product, so that the net results show a very considerable reduction in the manufacturing cost. Indeed, the rapid increase in the use of electric heating equipment is in itself proof that the advantages accompanying the use of electric heat in many cases outweigh an additional cost of the electric heat unit which may exist.

Coal and coke are relatively difficult and expensive to store and fire, and natural gas is restricted to comparatively local areas. Further, the supply available at present is such that it is not entirely dependable. Artificial gas is rather expensive, and it is not always obtainable in quantities, so that fuel oil naturally has become the chief source of heat in many of our industries, due to the convenience with which it can be stored, handled and distributed, its concentrated thermal value, and its past relatively low cost and abundant supply.

Accordingly oil has been a popular fuel and its use has become widespread. However, the very considerable increase in its cost, recently, and its apparent scarcity, have brought about a condition which is very trying to industrial managers, many of whom have become interested in electric heating as a solution of the fuel problem as well as many incidental problems.

It is proposed, therefore, to show very briefly some of the later applications in which electric heating has met with marked success, and to indicate some of its possibilities.

In general, the advantages of electric heating are recognized, but the impression seems to prevail that the cost of operation is excessive. This is true in certain instances—for example, in cases where the nature of the process permits the recovery of waste heat from the flue gases. Electric heating has been successfully applied over the entire range of temperatures, from low-temperature ovens for drying and baking, to high temperature

furnaces for melting and refining, so that equipments are available for many applications.

Electric ovens for baking enamel are used so widely, and their advantages so well known, that it is hardly necessary to do more than refer to them here. Their extensive use for enamelling automobile bodies and parts—in other words, where a superior finish is required—is sufficient argument as to their economy. Ovens for baking foundry cores also are yielding excellent results from the standpoint of efficiency and net cost—particularly for small cores, in which breakage and loss from uneven baking usually is a very considerable item. The uniform distribution and automatic temperature control possible with electric heat, considerably shorten the time required for baking and produce perfectly baked cores, so that the losses are reduced and rejects seldom occur. Several installations have been made in wire mills, all of which have showed a substantial saving. The following data are typical, and present the actual cost of baking steel wire to remove grease and drying it after pickling. These are operations which require no refinement, and it would not be expected that electric heat would have any advantages whatever if judged on a B.t.u. basis alone. The installation referred to has both electric ovens and coke-fired ovens of the same dimensions. Electricity is by far the most expensive fuel on a B.t.u. basis at drying and baking temperatures, as shown in Figs. 373 and 374, while coke is among the cheapest fuels. Therefore, the following direct comparison in the same plant is interesting.

BAKING AT 525°F. CYCLE 10 TO 12 HR.

Electric	Actual tests; output, 10 per cent	Tests; results reduced to 100 per cent output
Cost of power per net ton of steel	$ 5.087	$1.19
Annual charges per net ton	7.839	0.727
	$12.926	$1.917
Coke		
Cost of coke per net ton of steel	0.921	0.171
Annual charges per net ton	21.368	1.983
	$22.289	$2.154

BAKING AT 350°F. CYCLE 1 TO 10 HR.

Electric	Output, 35 per cent	Output, 100 per cent
Cost of power per net ton of steel	0.787	0.515
Annual charges per net ton	0.648	0.187
	$1.436	$.702
Coke		
Cost of coke per net ton of steel	0.253	0.146
Annual charges per net ton	1.766	0.510
	$ 2.019	$0.656

The normal output of these ovens is considerably less than the maximum capacity, so that "normal" results, or results from observation, are given, as well as results which might be expected if the ovens were operated at full capacity.

These figures show, as might reasonably be expected, that the cost of fuel in the coke-fired ovens is practically negligible in comparison with the cost of handling, repairs and other charges. In the electric ovens, the cost of power is the principal item.

Perhaps a more familiar example is an ordinary hearth-type furnace, as used for hardening tools, dies, cutters, etc. Tests were run on an oil furnace and on an electric furnace, both having about the same hearth area and doing the same kind of work at the same temperature.

	Electric	Oil-fired
Dimensions of heating chamber	30 by 36 by 22 in. high	48 by 24 by 20 in. high
Length of test (heating steel)	107 hr.	31.75 hr.
Average temperature held	1,450°F.	1,400°F.
Amount of steel heated	1,451 lb.	2,670 lb.
Amount of steel heated per hour	13.6 to 84 lb. (cal.)	84 lb.
Fuel and power to hold at 1,400°F.	8.04 kw.-hr. per hour (cal.)	1.65 gal. per hour
Fuel and power while heating steel	8.96–12.36 kw.-hr.	1.9 gal. per hour
Fuel and power rate	1.25 cts. per kw.-hr.	14 cts. per gallon
Fuel and power per pound of steel	0.65 kw.-hr. 0.147 kw.-hr. (cal.)	0.022 gal.
Cost per hour to hold at 1,400°F.	10 cts.	23.1 cts.
Cost of fuel and power per pound of steel	0.008–0.0018 (cal.)	0.0030

With both furnace tests corrected to the same output of 84 lb. of steel per hour at 1,450°F., the ratio of cost of oil burned to the electric power required is 0.0030 divided by 0.0018, or about 1.7. In other words, these tests show the cost of operating with oil to be 70 per cent greater than heating by electric power. It may be said that this electric furnace is provided with automatic temperature control and a time switch which throws off the power at the end of the working day and throws it on in the early morning, so that the furnace is always ready for use. This furnace and control equipment are shown in Fig. 375.

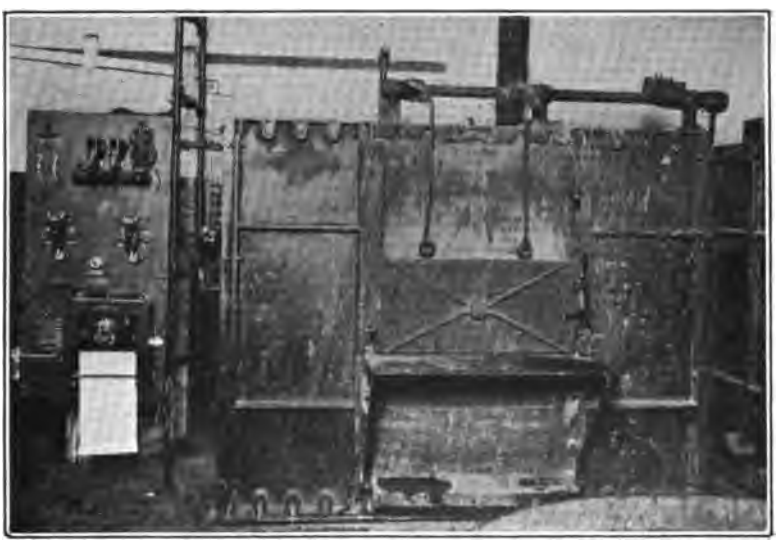


FIG. 375.—Electric resistance furnace with panel and instrument for automatic temperature control.

It is obvious from the above data that the fuel used in actually heating steel is almost negligible in either furnace, which is, of course, well known. The data show that the cost of maintaining temperature in the oil furnace is more than double the cost for the electric furnace. This may, perhaps, be surprising to many who base their calculations entirely on the relative cost of B.t.u. It would be still more surprising if the cost of repairs and fixed charges could be included in the comparison. This cost for the electric furnace is practically zero. The figures for this size of oil furnace are not available to the author, although they are probably obtainable from other sources.

without, thousands of others are doing the same thing. Society will not turn back now; presently it cannot turn back any more than it can today weave its own garments by hand. The convenience of today is the necessity of tomorrow. If we project the present trend of requirements even 10 or 15 years into the future, we begin to gain a true perspective of the imposing weight of the problem that industrialism faces. But there is little need to look into the future. The events of the past few years have given a foretaste of what lies ahead.

Thus the country is faced with a problem for which it must find a solution. The price of failure is too familiar a matter of experience to need recounting. If the issues involved were to stop here, if the only evidences of weakness were those manifest in the over-taxing of transportation, the problem would consist simply enough in amplifying the facilities of transportation in fuller keeping with the growth of demand. But transportation is already too large a factor in the composite of advancing costs, and the destiny of the country is already too largely at the mercy of the railroads, to make this form of solution either practical or desirable. What is needed is quite as truly relief *from* transportation, railway transportation at least, as the relief *of* transportation, and the logical procedure would seem unquestionably to consist in seeking the source of the trouble and what is needed by way of remedy.

Before doing so, however, it is interesting to reflect a little on the significance of what is involved. It is in the use of power, in the application of mechanical energy to performance of the menial tasks whether of the household or of the manufacturing plant, that the way has been opened up to social advancement. This menial service has to be provided for, if not through the medium of slavery, then through maintaining a numerically great submerged class in the face of inherent capabilities for advancement; and if not through the medium of this latter in turn, then finally through developing mechanical proficiency. Thus the development of democratic institutions on a comprehensive scale is bound up with the development of power usage; and it is not by any mere coincidence that the two have attained their maximum of development in American soil. So, too, as in the past, the nation which carries the development of power usage to the fullest advantage, bids fair to maintain the leadership among the nations of the world, at least as far as the practical

applications of democracy are concerned. This being the case it is unthinkable that the influences which now retard, even threaten presently to cut off, the further progress of mechanical proficiency, should be left to go unchecked.

The power materials include coal, water, oil, and natural gas. The last named, while of very real and woefully underestimated consequence as an energy resource, is too restricted to be counted among the enduring factors, and in the interests of brevity may be dismissed without further comment. The case of petroleum is somewhat different. In certain sections of the country, as notably in the whole Southwest, it is the main reliance for general power purposes; and elsewhere in the country it is similarly used to a certain extent, but not enough to have any vital bearing on the situation. Nor is it ever likely to; for the resource gives every indication of proving inadequate to the needs of the automotive engine alone; and while the importance of oil in this latter connection can scarcely be overestimated, it is of special order with no great bearing on the broad fundamental issue of mechanical work as against human labor. Accordingly, however important in its own particular field of power application, oil, like natural gas, may be dismissed from further consideration.

This leaves only coal and waterpower. Of coal the United States has in its underground reserves over half of the world's known supply; and the country's waterpower, developed to theoretic capacity, would suffice to turn its every wheel and illuminate its every street and building. With the extent of the resources certainly there is no fault to be found. In the matter of distribution, too, the country is signally fortunate, for the regions worst off for coal are the best favored as to waterpower. Thus New England, the South Atlantic states, the Southwest, and the Pacific slope, together embracing over half the potential waterpower of the country, are all practically without coal and bear testimony to the complementary distribution of the two major power resources.

But this complementary relationship is only potential; for despite the advantages of magnitude and distribution that give water power claim to a ranking denied to petroleum and natural gas, the resource has not attained to any such authority alongside of coal. Only some 10 per cent of the total expansion in power consumption in recent years has been in the direction of waterpower. The present production of hydro-electricity in the

United States represents roughly the equivalent of 55,000,000 tons of coal, whereas nearly 400,000,000 tons of coal go into the production of steam power and carbo-electric power. The waterpower developed to date is around 10 per cent of that readily available, scarcely 3 per cent of the total open to development under elaborate arrangements for storage.

The favorite explanation for this laggard growth on the side of waterpower ascribes the whole trouble, either directly or inferentially, to the handicaps imposed upon private initiative by the faults of Federal legislation. The facts do not bear out such conclusion further than to accredit this factor with contributive importance. Federal permits are requisite to the development of 75 to 80 per cent of the potential waterpower of the country, the balance being accessible so far as Federal permits go. About 4 per cent of the restricted portion and about 25 per cent of the part outside Federal surveillance have been actually put to work. The discrepancy of 21 per cent between the two is impressive; but even granted that this is attributable wholly to Federal interference, which is not the case, it will be seen that the nondevelopment of three-quarters of the potential waterpower of the country remains to be accounted for on another basis. In other words, the quality of Federal legislation, even under sweeping concessions to its untoward effect, provides but a minor element in the complete explanation.

Three influences are recognizable as bearing directly on the situation:

1. *Adverse Legislation.*—Here the situation has been clouded by various issues of Federal, State, and individual rights, covering not only the immediate subject of power but sundry other uses, such as stream navigation, likely to be interfered with. In view of these complications, legislation has characteristically been framed with an eye toward legalistic ends rather than in the direction of a genuinely constructive economic outcome.

2. *Public Sentiment.*—There is a general feeling, natural enough in the strength of its hold, that in the beauty of the country's rivers, with their rapids and waterfalls, adheres a certain nobility of function whose grandeur is the common birthright of all. The surrender of this heritage to the interests of commercialized service is a line of conduct not likely to meet with public approval. Whatever of actual substance in the way of purpose is

to be recognized in the fabric of legalism, as noted under the previous caption, has been contributed largely in response to this attitude of public sentiment. The attitude has unquestionable justification and must be reckoned with. Those on the one side who would have it ignored are as far wrong in the solution of the waterpower issue as those who would give it unqualified heed. Yet the principle is recognized universally that the interests of beauty must give place to pressing needs of utility. This consideration alone would not give rise to disfavor in regard to waterpower development. The source of disapprobation lies in the lack of vivid appreciation as to the matter of need, coupled with the attendant imputation of surrender to vested interests. Accordingly, the waterpower situation can not be cleared up satisfactorily until the need for the systematic development of this resource is firmly established; until freight congestions, fireless homes, foodstuff costs, and other intimately personal issues are seen to be genuinely involved; until the opportunity for the restrictive furtherance of special interests, financial or sectional, has been eliminated. Until these conditions have been met, attempts to promote the development of our waterpower resources are bound to result in ineffectual compromises.

3. *Cost.*—A hydro-electric station, once established, is largely self-contained and automatic in operation. There are no periodic items of cost for fuel, for its freightage, haulage, handling, and the like, such as associate themselves with the operation of a steam power plant. So, apart from such incidentals as administration, insurance, taxes, and depreciation, which together bulk small, practically the whole burden of gross operating expense is that assumed at the outset in the guise of initial cost and perpetuated in the form of interest money.

Thus the cost of money, displaying itself in bond interest, is the determining factor in the cost of hydro-electric power, precisely as the price of fuel, with its accompaniment of expense, determines the cost of steam power. The cost of money in this country, on a strictly commercial basis, is high. The prevailing rate of interest demanded of waterpower developments is around 7 or 8 per cent., which, with discounts taken into consideration, normally means a demand amounting to 9 or 10 per cent. on the working proposition. Estimate after estimate the country over has gone to show that only the waterpower site especially favored by natural advantage is susceptible to development under these

conditions in competition with the prevailing cost of steam power. These favored examples also frequently provide a bone of contention over which conflicting interests raise a great to do, tending to create the impression that the waterpower resources of the country constitute a tremendous asset whose possibilities are being withheld arbitrarily from their normal course of unfoldment. Nothing could be much further from the truth. With the exception of the new conspicuous instances that serve as a stimulus in keeping the question alive, no particular significance attaches to the country's undeveloped water power under existing conditions of finance, or will, until either these conditions have been lived down or steps have been taken to better them. The former represents a tendency which, left to itself, is not likely to yield anything of consequence for years to come. Nor is there any room for hope in technological advance. The issue of cost is a matter which, like the legal and sentimental obstacles just outlined, must be overcome, and the only way in sight lies through arrangements which will impart a degree of stability to waterpower securities such that they will receive the benefit of a reduced rate of interest.

Thus the influences holding back waterpower development are of a threefold order. These do not operate separately, but in conjunction with one another. Waterpower development stands in need of special consideration; instead, it meets with special opposition. There is none to work in its behalf except those with special objects in view, and the recognition of this quality in their efforts has gone to establish opposition. The contention in this wise has grown to be organized on both sides, with each alike oblivious to the real community of interests involved and legislative action caught fast in an entanglement of compromise. But back of these specific obstructions is the lack of economic pressure to break through them. The main features of the economic setting responsible for this lack of pressure are two: one is concerned with the relation between the power resources; and the other with the force of convention in respect to power usage.

In the first place, coal and oil have been so bountiful in this country that only the richest portions of these resources are worked; a project contemplating the development of a water power site faces this situation. It is evident that the cream of the waterpower source has demonstrated its capacity to compete with the cream of the fuel resources, and it is a fair assumption

that the balance is reasonably even in this area of rich values. But most of the cream, aside from that withheld by Federal restrictions and assiduously sought after by special interests with a taste for such matters, has been skimmed from water power, while it has not yet been exhausted from coal and oil; and the average of hydro-electric power, under present conditions, can not compete against the residuum of cream now being removed assiduously from the other two. But the course of preferential skimming will tend to equal matters up, and a steady increase in the significance of the waterpower resource is to be anticipated.

In the second place, and viewed from the standpoint of the large consumer of power, the use of fuel is the established convention for covering the needs for power. Where steam power is wanted, fuel of course must be used. But even where electricity is required, fuel is usually the most convenient source. For purposes of generating electricity the primary power is ready at hand in the case of operations already established on a steam-power basis, while for the service of expanded or newly projected operations the simple expedient of enlarging or at most erecting a steam-power plant is all that is necessary. In either case the first cost is low, and the chief element in outlay is the expenditures under the heading of fuel purchases, which follow along steadily, but are distributed over the subsequent years of operation. The current proceeds from these operations are counted on to care for this train of expense; hence, from a pecuniary standpoint on the part of a given industrial activity, there is no occasion for advance effort in capitalization under this head beyond the amount called for in connection with the subordinate item of cost for the erection and equipment of a steam-power plant. In the case of hydro-electric development, on the contrary, the conditions are reversed, and the whole weight of emphasis falls at the outset on the initial cost of power-site development. The running cost of hydro-electric power consists mainly in the single item of interest money on the capital represented in the initial outlay. An analogous condition would obtain on the side of coal-generated electricity if a given enterprise were called upon to provide an adequately equipped coal mine in addition to the power plant itself. In the one instance, as matters now stand, the coal mines already are established in lavish numbers and do not enter into investment calculations;

in the other, the power sites, with choice exceptions, still lie fallow and have yet to be developed if they are to be used. This is the situation facing any given industrial enterprise, however large, in respect to establishing its source of power. For the hydro-electric alternative to be chosen, it must present more than equal advantage. Indeed, it must be decidedly preferable, for projects in process of formulation or expansion are apt to find their capitalizing ability pretty fully exercised without taking on the development of any special source of power, whether in the nature of a coal mine or a waterpower site. Hence, in the process of natural selection exerted by business enterprise, water power is usually set aside as presenting claims inferior to coal.

This holds true not merely for manufacturing projects but for purely electric-power projects as well. No exception is found even in these common instances of municipal electric-power supply, where the bulk of the consumption is on the basis of pay the price or do without. What is the use, in these cases, of undertaking the tremendous extra effort connected with developing a special waterpower source, even granted an ultimate saving in cost? A public-utilities commission would in all likelihood force a corresponding reduction in price, and all the effort would come to nothing really worth while, since these projects are in the nature of public service corporations. The public at large can be relied upon to pay any price conventionally established just so long as the actual cost of production is sufficiently high to prevent the rate from being too extortionate; hence no one gains by lowering the cost of production—except the public, which goes, therefore, to no account. A special price even may be quoted to industrial users to discourage the larger interests from generating their own electric power, since they have a choice in this matter which the public does not enjoy. Thus the river that flows through the town has the beauty of its course unsullied by commercialism. Instead, a trolley park, with merry-go-rounds, dancing pavilions, loop-the-loops, and the like, occupy the power site. With its art and enterprise thus catered to, American municipal life in plentiful instances, not excepting that of the Capital city itself, is disposed to rest content.

Thus industrially and civically alike the electric-power situation is stagnant, caught in a backwater of convenience, with the course of progress blocked by the obstacles of initial cost. But it is not hydro-electricity alone which has its progress thus

obstructed. Its case is conspicuous because the resource itself is cut off largely from employment and advertises the inadequacies of the situation broadcast over the landscape. The shortcomings with reference to carbo-electricity are not so obtrusive and hence not so notorious; they are not heralded openly by actual disuse, but are cloaked instead under conventional misapplication. Thus commonly as much as a fourth of the coal-fired power employed in centers of population has its energy applied in the form of electricity. Yet, with the rarest exceptions, this energy is transported to the centers of use in the form of coal and there the electricity is generated in steam-power plants. Electric-power usage has merely been appended to the established structure of steam-power practice, with the result that the employment of power has been facilitated greatly, to the further aggravation of the broad problem of transportation. Thus far the very force that has the capacity to correct the transportation evil has served merely to accentuate it. By virtue of electricity, more power is consumed, more raw materals are required, more goods are produced, more coal is freighted.

The distributive generation of electric power was natural enough and the only practical procedure so long as the use of electricity was small. But that time has passed. Electricity is now a commodity in everyday use, with a large and steadily growing aggregate demand; to adhere to the original practice bespeaks obsolescence. Such escape as has been made from the confines of stagnation has been almost wholly in the direction of hydro-electricity. So, in spite of the great amount of talk and publicity that centers around the waterpower issue, there is more evidence of basic progress on this score than may be found on the side of coal power. All that may be fairly said in dispraise of the progress of this country in respect to waterpower is likewise true as regards coal power. In fact, this country does not face a waterpower problem as such; the issue is more broadly a power problem, of which waterpower constitutes only one important segment.

Objection may arise at this point that a systematic generation of electricity at strategically located super-power stations is prevented by technological difficulties in the way of long-distance transmission of power to the points of use. It is true that there are many open problems in long-distance service of this kind, but these are by no means insuperable; yet, granting them full

weight and considering merely what has been accomplished already in connection with hydro-electric transmission, we find that transmission lines 100 miles in length are common, while those up to 250 miles in length are known and regarded as practical. If we accept, say, a 200-mile radius as a present standard, and consider the distribution of the coal fields of the country in relation to the centers of population, we find that circles may be drawn around centers of coal production which will embrace a considerable area and much of the industrial territory of the country. Thus, on the basis of present technical attainments alone, with no allowance for improvements under way, a large share of the current power demand could be supplied directly over wires from the coal fields.

Such a change in practice would operate to the relief of transportation and on this score contribute a country-wide advantage. But it also would create special industrial opportunities which would fall only within the reaches of the transmission systems. Hence, to plan a comprehensive development of the areas in proximity to coal fields, would be to emphasize and accentuate the advantages of environment which are already proving hurtful to the economic growth of the country as a whole. The economic gain that would come to outlying sections through the general betterment of transportation certainly would be more than offset by the economic losses resulting from the increased disparity in power supply. There is no occasion, however, to confine attention to coal-field developments without regard to the distribution of water power resources, which, as already noted, bulk largest in the regions lacking in coal. Rather than to single out the coal regions for favor, it would be preferable to take the opposite course, leaving the near-by sections to be served by freight-hauled coal and relieving the longer hauls by promoting the systematic development of outlying waterpower sites, and thereby not only help transportation but conserve the natural resources involved and diffuse industrial opportunity as well. But fortunately the two lines of action are not alternates. On the contrary, they enmesh in a singularly perfect manner and lead to a common end.

Current demand calls for the annual transportation and distribution of about 700,000,000 tons of coal. Much of this demand could be satisfied with no other commodity or form of energy. In fact, no small share of the existing inadequacy is

traceable to the exaggerated respect in which the attributes of electricity are held to the acceptance of its superiority and to the consequent half-heartedness of the attempts to contest its advances. This condition of affairs is especially noticeable in public service heating and lighting. Here the campaign was instituted along lines of special strategic advantage to electricity, and the gas industry, instead of shifting to new lines, accepted the defeat to which it was foredoomed, lost its main base of operations, and degenerated into conducting a species of guerilla warfare.

But chemical energy has its own special advantages in the matter of heat application no less than electricity, and the opportunity for development is certainly just as great in the one field as in the other. Any change in what is now open to modification in favor of electricity, it is safe to say, will be counterbalanced by the rate of expansion in new consumption. Thus, the best that may be hoped for is a check in the growth of the coal burden under which organized transportation is already staggering. To let this burden freely continue to increase, trusting the outcome to luck, is to court all kinds of trouble, if not disaster; yet, even with best efforts, there is little prospect of a diminishing requirement.

It would appear, therefore, that at best we must continue to deal with over a half billion tons of coal. This figure, then, may be taken as representing the minimum of actual demand that must fall upon transportation, the minimum of tonnage whose full utilization in consequence is called for. Primarily this enormous amount of coal is now consumed in order to gain the energy contained in it, all else being disregarded. But coal is something more than energy in material form; it is also a source of many valuable mineral products. Indeed, it is a veritable treasure house of values, in this regard far surpassing any other type of mineral substance. Upward of a thousand coal products are in use today, some of them filling needs less conspicuous but every bit as vital as that for fuel. And the development is still in its infancy. A few years ago few of these products were known. Chemical vision can see no limit to the further unfoldment in prospect. The boundary to this field is like the horizon, always in sight but never to be reached. There can be no full utilization of coal which fails to take these matters into account.

At the present time a very small proportion of the coal con-

sumed is adequately used. Putting to one side anthracite, which has an energy value merely and therefore yields a reasonable service in its crude state, and counting off about one-twelfth of the bituminous coal, the portion subjected to by-product recovery in connection with the manufacture of coke, we find that there still remains each year in round numbers a half billion tons of coal which are consumed in the raw condition with a total loss of the commodity values and an incomplete recovery of the energy. The sum total of this loss represents the margin between present attainment and full utilization, and may be presented in tabular form, as follows:

The question naturally arises, why this preponderant inadequacy in coal utilization? This is no simple matter to explain: the reply that the individual user, whether an industry, a community, or a householder, finds it cheaper to consume raw coal than to dispose separately of its various values is true, but superficial. That procedure is not cheaper for the users in the aggregate; also there is no lack of technological knowledge requisite to fuller recovery of the values in coal. The shortcoming, then, can not be due to lack of desirability or to lack of technique. The default must be credited against economic conditions. And since the United States in the past has possessed no activities engaged in shaping and stimulating industrial developments, the responsibility reduces itself to the fact that industrial enterprise has not seen fit to go into the matter. Either the opportunity has not been apprehended or industrial enterprise, cognizant of the situation, has not been interested. The latter is undoubtedly the true explanation. For this lack of industrial initiative a blend of several factors is responsible. In the first place, America has been full of opportunities for volume production, and consequently business enterprise has not been forced by the stress of narrowing industrial opportunities to turn to the far more complex field of multiple, or by-product, production; only where the opportunities afforded in this direction were outstanding and marked has the inducement been responded to. Secondly, any given project, on contemplating the prospect, faced a situation in which the establishment of production would yield by-products, the consumption of which required other industries which, in turn, would contribute other products calling for still further activities; hence a project at the source undoubtedly would see their contemplated output ranging off into hypothe-

TABLE CXXV.—THE NEGLECTED OPPORTUNITIES INVOLVED IN THE WASTEFUL USE OF COAL IN THE UNITED STATES
(All figures in round numbers and on an annual basis)

Present attainment		Possible attainment					
Coal inadequately used under present conditions (1918)	Recovered under present conditions	Available under present technical knowledge and ultimately recoverable under stimulus of constructive economic policy		Loss interpreted in terms of dollars, on basis of normal (1915) values	National meaning of loss under present circumstances		National gain from correct practice
500,000,000 ton	A small percentage of the energy.	Energy ...	At least double the present recovery. (On basis of widespread utilisation of gas in place of solid fuel, etc.)	$1,000,000,000+ in needless mining and transportation of coal.	Needless burden upon overworked railways. Smoke nuisance in cities, entailing untold destruction of civic betterment attainments. High cost of coal to consumer. Resource waste.	Inadequacy of coal-products industries. Problems in explosive manufacture.	Some relief to transportation. Complete elimination of smoke. Cheaper fuel.
		Nitrogen (ammonium sulphate).	5,000,000 tons. (On basis of 20 lb. per ton of coal.)	$280,000,000.....	Serious nitrogen problem, affecting field of fertilizers and explosives. Dependence upon Chile for sodium nitrate. Large expenditures for atmospheric-nitrogen plants. High cost of nitrogenous fertilizers, reflected in cost of food.		Nitrogen independence, contributing to food production and explosive manufacture.
		Benzol....	1,000,000,000 gal. (On basis of 2 gal. per ton of coal.)	$300,000,000.....	Undue dependence upon gasoline as motor fuel, contributing to overproduction and rapid exhaustion of the petroleum resource.		Contribution to supply of motor fuel. Advancement of good-roads movement. Establishment of large coal-products industry. Gains in new directions to be developed by chemical research.
		Tar.....	4,000,000,000 gal. (On basis of 8 gal. per ton of coal.)	$100,000,000..... Additional value of coal-products manufactured from benzol and tar.	Neglect of roads.		
		Total...		* $2,000,000,000....			Capacity for relieving cost of living, $10–$20 annually per capita. Gain to American industry.

* This figure is given as a concrete expression of the magnitude of the opportunity that faces this country in respect to coal, although the significance of the prospect is conveyed more truly in the two columns to the right. The matter, of course, can not be expressed in figures without qualifications which, therefore, must be accepted on a basis of the argument in the text. An element of double count in the summation is compensated by increments resulting from the course of advancement in multiple production.

tical regions not yet established; while a project, viewing the matter further out, would regard its proposed position as bearing some resemblance to an island in a sea of nondevelopment. The requisite reach of coordination was evidently not self-accredited on the part of industrial enterprise. Then, again, the field has opened up fully only of late, so that the full measure of the opportunity has not been long standing.

In addition to these considerations, there has been no competitive spur to action. The loss represented in the wasteful consumption of raw coal was not felt by any given industry, since the practice was universal and the cost under this head was a more or less uniform item which was shifted in its entirety to the shoulders of the consuming public. The need for advance was also not generally appreciated, inasmuch as there was plenty of fuel, transportation difficulties had not loomed up, coal products could be purchased from Germany, nitrate could be imported from Chile, and, in general, the whole matter of coal was taken for granted.

Hence industry had no particular incentive for entering into a new field which, while large, was intangible; moreover, industry, under the old order, faced decided limitations in its recognized inability to construct a *proportionated* demand for the whole range of prospective products. On the other hand, the public, which was actually paying the cost of the inadequacy, but under a disguised heading, did not see its concern in the matter, nor was public interest represented by machinery charged with acting on popular behalf; public utilities commissions, the nearest approach to such machinery, were notoriously weak and shallow; the Federal Government, lacking the pressure of public opinion, did not take up the issue. So the course of progress was short-circuited, and the tremendous possibilities in our unrivaled coal resources remain today practically untouched. The industrial progress of this country has been sustained by the mining of an ever increasing quantity of coal, until the very bulk of the total has become a critical weakness in this country's industrial life.

Such is the situation. The utilization of coal is extravagantly wasteful from beginning to end, the wastefulness is a matter of uniform practice not subject to improvement through avenues of individual enterprise, and, contrary to general notions, it is the public at large, not industry itself, which stands the loss from the

shortcomings in the situation and which is, therefore, primarily concerned in its betterment.

The public is concerned because it pays the bill rendered by present wastefulness and will reap the gain accruing from any progress toward competency. The net advantage will not merely represent the margin of value now lost, but in addition will include the border of advance added by the multiplication of values over those calculable from the standpoint of the present. The total gain can not be expressed in terms of exact figures; indeed, it is in no sense a fixed quantity, but entirely dependent upon the length to which the future carries the matter from its present chaotic stage. But apart from the prospect of future gain, the maintenance of the situation as it now stands is actually costing money. There is no apparent reason why fully coordinated development should not look toward a fairly complete recovery of at least the leading by-products in coal, and this prospect would definitely entail the doubling, if not the trebling, of the fuel efficiency derivable. This means that our present annual coal output could be made to more than double its service, or, accepting the current service requirement as a standard, that less than half the output can do the present work and in addition make heavy contributions to the supply of fertilizers, motor fuel, and chemical products. The aggregate loss, on the basis of this very modest estimate, runs well above a billion dollars a year, or over $50 for each family of five in the United States (see Table CXXV, p. 1147) Of such measure is the average man's pecuniary interest in the full utilization of coal.

Improvement in coal utilization, then, can not be relied upon to come from industrial stimulus alone, but must be brought into effect as the result of public interest in the matter. The natural means for starting toward this accomplishment lie in the direction of enlarged municipal gas plants, which will handle all the coal needed by the community, with the production of solid fuel, gas, and the by-products, ammonia, benzol, and tar.

Through the principle of multiple production, therefore, coal can be forced to render up its full quota of service. This is a new economic force, one scarcely recognized as yet as a principle which may be applied constructively. Yet the principle of multiple production has been gaining headway for years, and by means of it the multiplying needs of man are being met from practically a stationary range of raw materials. The rôle of multiple produc-

tion is enlarging rapidly; it represents a principle that must come into play more and more to relieve the strain falling upon natural resources and transportation. Through the agency of chemical knowledge, it serves to create a divergence of products, each the starting point of a second diverging series. The principle of multiple production is peculiarly applicable to coal and oil; only by the use of this principle, brought into effective action under the guidance of a constructive economic policy, can adequate value be extracted from these power materials.

The principle of multiple production and the principle of electricity are the two most important economic forces that have come into play during the current industrial order. Nothing since the introduction of steam power can be compared with either of them in significance. Both are radically at variance with the established order; both have a special bearing on the power supply as affording untold possibilities for marked betterment. Neither has won recognition in this field provocative of notable change in the basic conventions of procedure. Here each alike has been ignored, except in so far as its advantages have gained lodgment within the establishments of precedent. Of the two, electricity has made the greater headway; multiple production has not yet found an opening outside the confines of the coke industry and has succeeded in preempting only half of that field. Neither electricity nor by-product coal utilization has been neglected entirely, but the real possibilities for the common good so bountifully contained in each never have been cultivated in the least.

In the realm of power these two great agencies of economic advance are exactly complementary. Together they present a solution for the transportation aspects of the power problem, not to mention their bearing in other regards. The principle of multiple production enables the full utilization of the whole range of values transported in the form of coal. Electricity makes it possible to transmit *energy* where energy alone is required and thus frees the ordinary channels of transportation of a needless burden of bulk haulage. The first would determine the quantity of coal needed and insure the adequate employment of that quantity; the second would make it unnecessary for the railways to haul more than the total thus determined. The outcome merely waits upon the application of these two economic forces in effective coordination.

CHAPTER XXIV

FUEL CONSERVATION, PRESENT AND FUTURE

By

Horace C. Porter*

INTRODUCTION

It is a principle of economics, now well recognized, that prosperity, evinced by steady employment for all at living incomes, must come first through an adequate rate of production of the world's goods, and second, but hardly less important, through increase of efficiency in the use of expendable goods. The importance of fuel in the economic scheme is illustrated by the fact that the fuel bill of the United States for 1920, if apportioned to each wage-earner, would constitute at least 15 per cent of the average income. A large part of this bill resulted from extravagance.

Progress, however, is being manifested in the application of fuel; in an improvement of methods, and a rise in the curve of efficiency, as well as in that of total consumption. Today, resulting from increased use of scientific methods, we see greater returns per ton of coal than 10 years ago. Could the old and wasteful equipment be scrapped more rapidly and new investment in modern plant be financed more readily, undoubtedly a more rapid rise in the efficiency curve would result, and fuel consumption, per capita, might attain a maximum or start to decline. By known and proved methods the present output of power and heat in this country could be obtained with one-third less expenditure of fuel. The adjustment is proceeding, but there is still room for much progress.

Per capita consumption of fuel in the United States increased about 12½ per cent. in the last 10 years—from 152.4 to 171.8

* 1833 Chestnut Street, Philadelphia, Pa.

millions of B.t.u. The increase* has been principally in oil and gas. It is cause for congratulation that, notwithstanding great increase of industrialization, elevation of standards of living, and the devoting of vastly increased industrial yields to the benefit of other nations, as well as ourselves, we have maintained so small an increase in fuel consumption.

Fuel production seems at times, however, scarcely able to meet the demand. Under the trying conditions of the last few years, transportation deficiency has retarded fuel distribution and production, so that often a real shortage has existed. The loss of over 50,000,000 tons from the normal coal production during the nation-wide coal strike of 1919 contributed in important degree to the holding back of needed improvements and new construction in industry, which later made urgent demand for more fuel. Exports from tidewater leaped to 600 per cent in 2 years about that time and during the last half of 1920 were at the rate of 26,000,000 tons per annum. Stocks were dangerously low in the early part of 1920 and had to be built up.

Coal production, therefore, in 1920 reached 645,600,000 tons, a total within 1 per cent. of that of 1917 and within 5 per cent of 1918, years in which war demands were large. But distribu-

* These figures are based on the following, taken largely from published statistics of the U. S. Geological Survey and the Census, except that certain items, such as exports (of oil, crude and refined) and changes in stocks (of both coal and oil), have had to be estimated and are approximate only.

	1910	1920
Population of the United States (millions)	92.0	106.0
Coal produced, millions of tons	501.0	646.0
Deduct exports and additions to stocks	14.0	58.0†
Net coal consumed	487.0	588.0
Coal consumed, per capita (tons)	5.29	5.55
Petroleum produced and imported (millions of barrels)	210.0	550.0
Deduct exports, lubricants, etc., and additions to stock	57.0†	160.0†
Net petroleum consumed for fuel	153.0	390.0
Petroleum consumed per capita (gallons)	70.0	155.0
Natural gas consumed (billions cubic feet)	510.0	670.0†
Natural gas consumed per capita (thousands cubic feet)	5.54	6.60
B.t.u.'s consumed per capita, in coal (millions)	137.5	144.3
B.t.u.'s consumed per capita, in petroleum	9.6	21.2
B.t.u.'s consumed per capita, in natural gas	5.3	6.3
Total	152.4	171.8

† Estimated, in part.

tion was at fault and during a considerable part of the year the requirements of trade and industry were not met. Quick reaction followed early in 1921 and business depression lowered rapidly the demand for fuel until coal cars were everywhere idle on sidings and mines were operating at 40 per cent.

Greater regularity in production and distribution of coal is highly desirable from many standpoints and not the least on grounds of conservation. Much fuel would be saved if the consumer's demands could be met steadily through storage reservoirs both at mines and points of delivery. Coal of greater uniformity would be mined and it would be devoted more generally to purposes especially suited to the various grades and qualities.

World reconstruction urges upon us the use of additional fuel. To emerge from the transition period of 1919–20 and begin in earnest the replenishment of the world's capital, industries must be given the necessary coal and oil. America, with a coal production 46 per cent of the world's, will assume a major part in reconstruction, for which the amount of fuel necessary will be governed in important measure by the degree of efficiency and conservation attainable.

CONSERVATION METHODS

Professionally, to the industrial chemist and engineer, conservation in use appeals as a most important aid in removing or reducing fuel shortage. A reasonable and practicable increase in fuel economy would help materially in bringing supply and demand closer together. In consequence of it, also, would be exerted an influence toward lowering of prices. Notable advance has been made during recent years, but the practical maximum of efficiency has by no means been reached. Although the human tendency to use available natural resources to the limit, with little regard for posterity, is not to be overlooked or minimized, still in times of shortage economy and efficiency make stronger appeal to the consumer with a view to cutting down requirements and reducing raw material costs.

Many of the expedients for raising the efficiency of fuel utilization are of such a nature as to require large changes of existing plant and equipment—such as, for example, the centralization of power development in superpower stations, the electrification of railroads, and the replacing of non-recovery

beehive coking of coal by by-product recovery plants. These changes go slowly, and depend greatly on general financial conditions and the prevailing cost of capital outlay. Other expedients will afford in the meantime quicker realization of efficiency gains, not as large, but yet of distinct importance in practical conservation.

DISTRIBUTION OF COAL CONSUMPTION

The following tabulation of the country's bituminous coal consumption in 1917 by classes of users, is taken in large part from the U. S. Geological Survey reports, and is coupled with an outline of some of the means whereby conservation may be and is being accomplished in the different fields without great delay *

PRESENT CONDITIONS AND MEANS OF IMPROVEMENT

The coal distribution chart for 1917 shows that fully seven tenths of the coal consumption is devoted to steam raising under industrial and locomotive boilers and to the operation of industrial furnaces, largely for melting or reheating of metals. It is in this large field that perhaps the most immediate opportunity for improved efficiency exists.

Boiler-Furnace Efficiency.—Boiler furnaces consume roughly 330,000,000 tons of coal a year in this country, of which 130,000,000 tons go into the heat losses in making steam, some unavoidable, others reducible by practicable methods well known, but neglected. The human element is no doubt a very large factor in the neglect of this potential conservation: the inertia of small-plant managers fearing high overhead cost in applying improvements to small units, and the unreliability and incapability of much of the boiler-room labor available. Concentration of power production into larger units will tend toward improvement in these respects.

In boiler-furnace economy roughly half of the efficiency losses are due to heat carried away in the chimney gases: under com-

* Later statistics than these are available, namely those for 1918, but they are not as complete, and furthermore they represent conditions in an abnormal year affected by unusual war demands. In 1920 the notable variations from the distribution figures of 1917 were in exports and in coking. In exports (bituminous only) for 1920 there were 32,700,000 tons or 5.9 per cent of total production, while in coking 76,840,000 tons or 13.8 per cent were used, 7.9 per cent in by-product and 5.9 per cent in beehive coking.

BITUMINOUS COAL DISTRIBUTION—1917

	Bituminous coal used (net tons)	Per cent. of total consumption	Practicable means of conservation
Industrial Power: (Excluding all coal for steel and iron mills and coking)	130,150,000	23.4	(*a*) Increased use of economizers, superheaters, feed-water heaters, and mechanical stoking. (*b*) Care in firing, with control of flue-gas composition and temperature. (*c*) Use of gas engines in conjunction with steam, on power plants where variable load thus can be met economically. (*d*) Economy in disposal of exhaust steam.
Steel and Iron Industry: (Excluding coking)	90,000,000	16.2	(*a*) Increased use of gas for heating and power, and of regeneration and recuperation. (*b*) Increased use of waste heat for steam generation. (*c*) Powdered coal and tar in heating furnaces.
Beehive Coking:	52,250,000	9.4	(*a*) Gradual abandonment in favor of by-product coking. (*b*) Utilization of waste heat in boiler firing.
By-product Coking:	31,500,000	5.7	(*a*) Increased utilization of waste heat through regeneration, recuperation and steam generation; increase in surplus gas and its utilization.
Railroads:	156,150,000	28.0	(*a*) Use of feed-water heaters and economisers on locomotives. (*b*) Economy of steam pressure by idle locomotives.
Domestic:	57,100,000	10.2	(*a*) Avoidance of unnecessary heat in unused places and of excessive temperatures when not needed. (*b*) Economy of gas used as fuel by adjustment of appliances.
Other Uses: (Gas manufacture, 0.9 per cent; export, 4.3 per cent; bunkering and miscellaneous, 1.9 per cent)	39,700,000	7.1	(*a*) Discard of candlepower standard for gas and adoption of more efficient gas manufacture.
Totals	556,850,000	100.0	

monly prevailing conditions an increase of 1 per cent. in CO_2 in the chimney gases means a lowering of the excess air by about 10 per cent, an equivalent reduction in the B.t.u.'s carried away in sensible heat, and a gain of 1.5 to 2 per cent in the combined efficiency of boiler and furnace; a lowering of the flue gas temperature by 100° F. means an additional gain of over 3 per cent in boiler and furnace efficiency. It is somewhat startling to those who have not stopped to consider the matter carefully, to find that, for every pound of coal burned, 15 to 25 lb. of chimney gases result, carrying out their sensible heat to waste. These efficiency gains are not in large figures, but they mean a good deal when applied to the large tonnage of boiler fuel used.

Superheaters and feed water heaters, if more generally applied, would add further to the saving. D. D. Pendleton* has recently estimated that only 15 per cent of the steam-raising capacity of the country is equipped with superheat, and that the remainder not so equipped would gain between 14 and 20 per cent in efficiency by its use.

Railway Locomotive Operation.—In railway locomotive operation it is true that considerations other than those of thermal efficiency are highly important in obtaining the driving capacity required. On the other hand, there are opportunities for fuel saving here, and it is a big field in point of total consumption. In an article on locomotive feed water heating, T. C. McBride† has recently claimed that devices for this purpose utilizing the exhaust steam save on locomotives 10 to 13 per cent of the coal used as compared to injector operation. The maintaining of high steam pressure unnecessarily in locomotives standing idle in yards—in other words, the preventable part of the so-called stand-by losses—is, no doubt, a factor in the large railway consumption of coal.

Industrial Heating Furnaces.—A great deal of coal is used in industrial heating furnaces for the heat treatment and re-working of metals, the rolling and forging of steel, and for tempering processes. Before the British Royal Society of Arts, H. M. Thornton‡ has lately brought out the great advantages and economy of gas as a fuel for these furnaces. Records are presented showing comparative results in various sizes and types

* *Blast Furnace and Steel Plant*, **8** (1920), 350.

† *Mech. Eng.*, **42** (1920), 283.

‡ *J. Roy. Soc. Arts*, **68** (1920), 346.

of furnaces, from the small rivet heaters to the large forging furnaces, the saving in fuel cost, as compared to direct coal, coke and oil firing, ranging from 40 to 60 per cent. Indirect advantages also result from increased capacity per unit and decreased labor cost. W. Trinks,* of Pittsburgh, has been these economies in the use of gas and of powdered coal in a series of articles on heating furnaces, recently published. Trinks is pessimistic as to the practicability of such savings, owing to the human tendency of firemen to waste fuel when they can do so easily by the turning of a valve. It would seem, however, that, under the inducements of a bonus system, this same ease of turning a valve might prove a factor leading to conservation.

An actual record is given by A. A. Cole,† of a powdered coal installation in a large heating furnace used in the manufacture of rolled steel wheels, wherein an economy of 30 to 40 per cent. over direct hand firing was obtained, and a labor saving equal to 15 per cent of the fuel cost.

At steel plants where by-product tar, an excellent fuel for the open hearth furnace, is available, greater value frequently can be obtained from the tar as fuel, based on comparative coal cost at the plant, than is obtainable in the open tar market.

Changes in open hearth and heating furnace construction, designed to regulate combustion and length of flame, are proving in actual plant trials to effect an increase in metal output, reduce waste heat losses, and raise fuel economy by 10 per cent, without impairing the life of the furnace.

Waste-heat Boilers.—More attention to waste-heat losses on industrial furnaces and in the older by-product coke plants, with increased use or more efficient use of regeneration and recuperation would pay well in fuel saved, resulting at the coke plants, for example, in added yield of surplus gas. Waste-heat boilers are now used on many industrial gas-fired furnaces and coke ovens. Cement-burning furnaces on powdered coal have made a good beginning in saving the heat of their waste gases by boilers. These applications could be extended widely with profit and an important degree of fuel economy. Brick and pottery kilns, copper and zinc furnaces, and beehive coke ovens show waste-gas temperatures from 1,200 to 2,000°F. A large steel plant near Pittsburgh operates waste-heat boilers on the outlet

* "Blast Furnace and Steel Plant," **8** (1920), 327.

† *Ibid.*, **8** (1920), 417.

flues of its rectangular non-recovery coke ovens, obtaining thereby a steam output which has reached 27 hp. per oven. On the basis of the amount of coal coked in the oven per hour, of which only a little more than one-third is burned, this result amounts to about 0.7 hp.-hr. per pound of coal coked, or roughly one-quarter of the average yield ordinarily obtained from complete combustion of similar coal in boiler furnaces.

Miscellaneous.—Large gas-engine driven power stations are being used by steel works on blast furnace gas with conspicuous success and large fuel economy, as at Gary, Ind., by the U. S. Steel Corporation, and at Sparrows Point, Md., by the Bethlehem Steel Corporation. Such means of power production can be extended and a saving effected in coal more than equivalent on a B.t.u. basis to the blast-furnace gas otherwise wasted, owing to the comparatively high efficiency of the gas engine.

Anthracite coal is being reclaimed from the river bottoms in eastern Pennsylvania, and from the culm banks by washing and briquetting. Culm also, experimentally, has been mixed with pitch or bituminous coal and carbonized.

In the domestic fuel field, comprising 10 per cent of the bituminous consumption (or 17 per cent, based on both anthracite and bituminous), the greatest economies eventually will come from increased use of gas and carbonized fuels. The domestic field will be one of comparatively low efficiencies, however, as long as small sized fuel burning units remain. Economies can be made by using care as to overheating of houses, particularly of unused portions of houses. Furthermore, in the burning of gas in domestic appliances, it has been shown by recent experiments at Ohio State University* that efficiency of utilization of the heat may vary from 16 to 40 per cent, according to the distances of the burner from the vessel heated.

FUTURE POSSIBILITIES

For the future, with the steady and permanent growth of fuel economy through gradual adoption of major improvements requiring time and large capital outlay, there is reasonable prospect that the per capita fuel consumption in this country may reach its peak and begin to decrease.

Electrification of Railroads.—The most striking possibility among these major improvements looking to fuel conservation,

* *Mech. Eng.*, **42** (1920), 287.

is the electrification of railroads. It has been figured carefully by A. H. Armstrong, of the General Electric Company, for the Committee on Electrification of Steam Railroads, National Electric Light Association,* that by universal electrification of steam railroads in this country a direct saving of 122,500,000 tons of coal per annum, two-thirds of the present railway fuel consumption, would result. This leaves waterpower out of account and compares results on the basis of steam-generated electric power in central stations. Deduction is made from the present steam engine ton-mile movement for company coal haulage on cars and tenders.

The Chicago, Milwaukee and St. Paul Railway has had in successful operation for over 4 years large electrified portions of its system in Montana and Washington. The electrification now totals 645 route miles. Power is purchased from the Montana Power Company. In a detailed statement of actual operating costs made to the National Electric Light Association, R. Beeuwkes, of the Milwaukee and St. Paul Company, compares steam operated and electrically operated divisions in respect to those items of expense affected by the type of motive power used. For the totals of these items electrical operation shows about 40 per cent lower cost; and for the one item of train locomotive power cost as against locomotive fuel used, the saving amounts to 53 per cent, not taking into account the cost of fuel haul.

These are direct savings, exclusive of the manifest indirect advantages accruing from the release of freight cars by gain in speed of haulage, the release to revenue-bearing traffic of coal cars now hauling railway coal, the avoidance of boiler feed-water expense, the improvement in reliability and safety of railway service, and the increase of property valuation around railway terminals. Most of these items will aid in decreasing the menace of fuel shortage in the future.

High cost of installation, and the present difficulties in the way of financing railway betterments, will act to retard this great step in the progress of fuel conservation. The passage of recent water power legislation by Congress should, however, exert a large influence in furthering such projects. Waterpower development under favorable Government regulation not only affords low cost power, but releases coal-car equipment in greater meas-

* See *reports* of this Committee, 1920.

ure than would central steam stations. President A. H. Smith, of the New York Central Lines, has stated, "It is known that, generally speaking, the operating cost (exclusive of fixed charges) of electric service is less than it would be for a similar steam service; . . . the further extension of electric operation on steam railroads depends to a considerable extent upon the cost of electric power . . . There is a point where the cost of coal will cause the price at which electric power is available to the railroad to result in sufficient saving . . . to warrant the expenditure for electrification."

Centralization of Power Systems.—The central "super-power" station for general power service, gradually displacing less efficient scattered units, will effect large saving of power-plant fuel. The war aroused all nations to a realization of the importance of reliable and adequate industrial power, efficiently produced, for maintaining industry and national effectiveness at the maximum. The British Fuel Research Board and the Nitrogen Products Committee have made, and are continuing, comprehensive studies of power development centralization. Our own Congress has provided $125,000 for investigation of a possible super-power project for the Boston-Washington district.

There are installed now in the United States, or nearing completion, central power stations aggregating about 350,000 kw. capacity which use coal at or near the mine mouth. These stations are laid out for an ultimate capacity at least double that of the present installation. They are consuming coal at an average rate of about 2.0 pounds per kw.-hour on the switchboard, one-third less than the average consumption of public utility power plants throughout the country, as shown by statistical reports of the U. S. Geological Survey.

The advantages gained from the saving of freight on coal and in reliability of service, add their weight to those resulting from increased fuel economy shown by the above figures. Reduction of overhead and labor cost, and of the capital charges per unit of power output unquestionably follows centralization into large operating units, the gain being emphasized by so choosing conditions as to permit of operation under a highload factor. For this reason a super-power station project may well take into account the disposal of its output to such classes of consumers as would tend to equalize the load, possibly to chemical and electro-chemical industries which can use power during the "off-peak" periods.

By-product recovery in connection with centralized power development commends itself, on grounds of conservation, to most careful investigation. Direct coal-fired steam-turbo-electric stations afford a high degree of fuel economy, but they waste entirely a valuable national resource in the nitrogen of the coal, vital to agriculture and to munitions of war. Notwithstanding this fact, the Nitrogen Products Committee of the British Ministry of Munitions, after thorough investigation of various systems of power production from coal, came to the conclusion that the net cost of power in processes involving carbonization or gasification of coal and burning of the resulting coke and gas under boilers was higher than in direct coal-fired steam turbine stations, allowing a fair market value to the by-products. Both high and low temperature carbonization were considered. The possibility of using gas engines for power was dismissed by the Committee as entirely impracticable for stations of the size necessary for competitive operation under British conditions. The reason advanced was the very high capital cost of such installations and the cost for labor and repairs.

These conclusions do not necessarily apply with equal force to the American problem of centralizing power development for miscellaneous demand under more widely varying load. Gas engine power plants of 50,000 kw. capacity on blast furnace gas, in units of 2,000 to 5,000 kw., are operating successfully in this country at costs for labor and repairs not materially higher than those for equivalent steam turbine plants. It appears that, with due consideration of the returns from sale of by-products and with due care so to restrict the scale of operation as not to overload the by-product market, investigation might show worthy of trial a combination, wherein gas power would be used to meet in some measure the steady portion of the plant load and coal-and-gas fired boilers the variable load, generating gas by methods of highest thermal efficiency and with by-product recovery. Surplus gas could be sold to gas companies for mixing with their manufactured outputs, or for reinforcing the waning supply of natural gas.

Expansion of By-product Recovery and Gas Making.—The problem of choosing the best system for production of gas and by-products in such central stations or for public gas distribution is a many sided one. To go into a detailed consideration of it

here would take us too far afield. A very important phase of it requiring investigation is the mechanical problem of proper design of gas engine to use gases of high-hydrogen content. This may or may not have been worked out sufficiently at the present time.

The gas-making process to be used in such an installation would be one permitting economical recovery and high yield of ammonia, and at the same time affording the highest thermal return from the coal. Certain processes now in various stages of development for the complete gasification of coal by alternate production, in the same generator, of distillation gases and of water gas by superheated steam, show indications of being capable of higher thermal efficiency than the two-stage gasification systems now prevailing, wherein coal gas is made in ovens or retorts and water gas from the resultant coke in separate generators. Mixed gas, made by the single-stage complete gasification, would have a heating value of about 320 to 350 B.t.u. per cubic foot, a ton of coal yielding about 50,000 cu. ft., if completely gasified. Ammonia would be obtained in higher yield per ton than from present carbonization processes. Other valuable by-products would be recovered. The possible use of oxygen produced electrolytically from off-peak power, to enrich the blast in such gas generators, is worthy of investigation for the sake of lowering the content of nitrogen and hydrogen in the gas.

It may be found practicable in the future, when low-temperature carbonizing processes have been developed further, to make use of them in such a central station to a limited extent, possibly for enriching or raising the heating value of the mixed gas and for producing a clean, smokeless, solid fuel for disposal to the domestic and small steam trade. Central power stations distributing electric power only will not displace steam plants for heating purposes, or for chemical manufacture, dyeing, bleaching, etc. It would be desirable in the interests of conservation that carbonized fuels and gas, if by manufacture in large central stations they can be made cheaply enough, should be used increasingly for this purpose.

The trend in public gas supply is toward the abolishing of lighting standards and the substitution of a thermal requirement lower than has prevailed in the past. Steps have been taken to this end in the majority of States. New Jersey recently has adopted a 525 B.t.u. standard; the city of Philadelphia has agreed

provisionally to a 530 standard; Massachusetts has 528, and many other sections of the country are similarly progressive. This means a lowering of the previous requirements by 75 or 100 B.t.u., and will result in immense savings of oil in water gas manufacture. It will permit also the use of by-product coke oven gas unenriched, and in coal gas manufacture the steaming of retorts to give greater yields of both gas and by-products, the increased gas yield permitting still more conservation of oil in carburetting water gas. The cracking of oil in water gas manufacture is a wasteful process at best, in yielding soot and tar in place of available heat units, and having lower thermal efficiency than the direct burning of oil as fuel.

If gas companies were to be permitted still further reduction of heating value, with adjustment of rates to accord with the lower cost of manufacture, there undoubtedly would result, particularly in the industries, an extension of the use of gas, the fuel "de luxe" whose convenience and many attendant economies, mentioned earlier in this chapter, easily expand its sales if the price is not at too high a premium over that of other fuels.

By-product coke ovens are increasing steadily in number, but in 1920, 40 per cent of all coke still was being made by the old non-recovery process, which burns 10 per cent of the coal and all the gas and by-products, in effecting the coking operation. If the 24,000,000 tons of coke made annually in beehive ovens were to be made in modern recovery ovens, it is safe to say that an economy of 8,000,000 to 10,000,000 tons of coal would result, this being an aggregate of the fuel equivalents of gas and tar saved, increased coke yield and improvement in blast-furnace fuel efficiency. Ammonia and benzol recovery would constitute an additional gain.

Conservation of coal by means of coking will grow as the outlet for coke and by-product grows. Extension in this field is not to be considered as limited by the metallurgical demand for coke. More competition, however, with coke and coke-oven gas as fuels to replace coal, is likely to arise eventually from cheap power developed in central stations (replacing small generating units) and from lower-cost gas made by complete gasification processes.

Colloidal Fuel.—Colloidal fuel deserves mention in connection with fuel conservation. Colloidal suspensions of pulverized coal in oil permit of the same economies in application as either

oil or powdered coal alone, and have some advantages, notably permitting the use of higher ash coals, higher sulphur oils, and many carbonaceous waste products, concentration of heating value in relation to bulk, and decreasing of fire hazard as compared to oil. However, it is of important bearing on the probable future development of this new fuel to consider the oil reserves available to the United States for fuel purposes.

CONCLUSION

The question is likely to arise, whether fuel conservation is of great importance when supply is ample, transportation is adequate and profits of fuel users are apparently secure. First, it may be answered, efficiency in the use of raw materials always makes for increased financial returns; second, waste promotes extravagance and raises the cost of living; and lastly, our high-grade fuel reserves are being exhausted at an alarming rate. George H. Ashley, State Geologist of Pennsylvania, estimates* that practically all the easily workable coal beds of Pennsylvania and West Virginia, 6 ft. or more in thickness, will disappear in 75 to 80 years at the present rate of increase in exhaustion. Low-sulphur coals, especially desired for metallurgical purposes, are becoming so scarce that steel men are investigating measures for getting along without them. Yet the high-grade low-sulphur Pocahontas and New River coals still are sold in large part for steaming purposes, where such low-sulphur content is not an essential quality.

Improvement never the less is being made in the direction of systematic and logical coal marketing and higher efficiency in utilization; there is a progressive tendency, in America, towards greater fuel economy, and future developments may decrease materially our per capita fuel consumption.

*By private communication, supplementing published report.

CHAPTER XXV

SOME PROBLEMS IN THE UTILIZATION OF FUELS

By

Raymond F. Bacon and William A. Hamor

The most efficient utilization of our wealth of fuel supplies is a subject which is being accorded constantly increasing attention. Interest in this topic in the United States generally has been confined to the advocates of the conservation of our natural resources. The fuel supply is still abundant and in industry it usually has been found to be a more convenient policy to burn high-grade coal, or fuel oil, than to be concerned with the problems encountered in the use of peat, lignite, or some of the poorer grades of coal containing a high percentage of ash. It also frequently happens that, in some mining districts, a portion of the coal is regarded as refuse, and is either burned to eliminate it, used for filling, or thrown on the culm piles. The reserves of bituminous coal and lignite in the United States are immense, but the supply of some of the higher grades of solid fuel, such as coking coal and anthracite, may be exhausted during this century, and accordingly the conservation of all classes of fuels can not be over-emphasized in its importance. Indeed, it merits the most searching inquiry. This chapter presents a discussion of some of the most important engineering problems in the utilization of fuels.

THE UTILIZATION OF LOW-GRADE FUELS

The present period of commercial and industrial activity in the United States and Canada,* in combination with the use of

* It may be mentioned here that a peculiar situation exists in respect to Canada's fuel supply; *viz.*, that, notwithstanding the enormous resources which Canada possesses in coal, over 50 per cent of the consumption is imported from the United States. The Canadian coal-fields are situated in the extreme east and in the western provinces, while the great central provinces of Ontario and Quebec, the principal centers of population, are more easily and economically supplied with coal from the coal-fields of

liquid fuels for automobiles and marine purposes, has accentuated the inadequacy of some of our commercially developed fuel supplies and has directed specific attention to the fact that certain known sources of fuel are being depleted rapidly. With the present limited development of our waterpower and of our deposits of low-grade fuel, the American nation is dependent largely upon localized mining activity in the regions where deposits of high-grade coal and of petroleum are found. Large sections of the country receive their fuel supplies by long rail or water routes. They are often subject to delays from the shortage of cars, locomotives, or shipping; from congestion of traffic or from transportation, or as the result of miners' strikes. The cost of freight usually prohibits the transportation of any but the highest grades of coal for distant consumption. In such parts of the country there are often undeveloped deposits of low-grade fuel which could be used locally, by several available methods, in connection with existing equipment. An accurate estimate as to the quantity of such fuel is difficult to obtain; but, based on the area in which it is found, the amount, unquestionably, largely exceeds the supply of fuel now being utilized commercially.

This fuel has been classified into two divisions, *viz.*, lignites and peats,* and graphitic coal, such as is found in the New England States and in the Canadian Northwest; and, in addition to these comparatively undeveloped sources of fuel, modern methods of

Pennsylvania. Further, no anthracite coal occurs in eastern Canada, and Canadians have grown dependent upon the anthracite output of Pennsylvania for that desirable domestic fuel, which is not only the main house-fuel in Manitoba, Ontario and Quebec, but is imported even into the Eastern coal districts of Canada. While such a condition of international trade attracts little attention during normal times, under conditions such as those which have been brought about by the European War, the importance the situation and its possibilities are fully realized. During 1920 Canada imported 11,548,475 short tons of bituminous round and run-of-mine, 2,312,754 short tons of bituminous slack, and 4,881,313 short tons of anthracite and anthracite dust.

* The following are some of the suggested lines of research on peat:

I.—Drainage.

(*a*) To investigate the properties of peat which have a bearing on the problem of the drainage of bogs.

(*b*) To determine the effect of drainage on the moisture content of the peat, and the rate at which the reduction of moisture takes place.

(*c*) To determine how the rainfall over bog areas finds its way to the drainage channels. In what proportion do the factors soakage, run-off, and evaporation, operate.

coal mining, together with the necessity for taking out the thinner veins, have resulted in an increase of mine waste which is not turned to use, but which possesses utilizable fuel value.

The reasons for the lack of development and utilization of low-grade fuels may be summarized as follows:

1. The cheapness with which the high-grade fuels could, in the past, be mined and transported to the markets.

2. The need of basic experimental and development work, which is required in order to utilize the full thermal efficiencies of such fuels.

THE USE OF LOW-GRADE FUEL FOR STEAM-GENERATING PURPOSES

Important work has been accomplished in power-generating stations in the direction of increasing the thermal efficiencies of the higher grade fuels; but much more investigation remains to be carried out along that economic line, particularly in the utilization of the full value of the fuel at high rates of combustion. High rates of combustion are, especially in large power plants,

II.—Drying.

(*a*) To investigate the relative importance of the various factors involved in the air-drying of peat fuel.

These factors are—

1. Humidity and temperature of the air, wind action, sunshine and rain.
2. Frost.
3. The size of the sod of peat and the effect of the maceration.
4. The character and chemical constituents of the peat.

(*b*) To determine whether the waste heat from exhaust gases or heat from gas specially burned can be economically employed to reduce the percentage of moisture in peat already partially air dried.

(*c*) To investigate the electro-osmotic process of separating water from peat.

III.—Economic Uses of Peat.

(*a*) To determine the most economic percentage of water in peat for producer work with recovery of by-products.

(*b*) To determine the most economical way of utilizing the energy obtainable from peat.

(*c*) To determine the best mode of preparing peat for domestic use.

(*d*) To find whether peat charcoal can be economically utilized for the preparation of calcium carbide.

IV.—Miscellaneous.

(*a*) To ascertain the effect of moisture, ash content, and humification on the calorific value of peat.

of extreme economic importance, the capital investment being reduced in direct proportion to the rates of burning. In nearly all the accepted types of boilers the efficiency of the absorption of heat at high rates of combustion is greater than that of the furnace in the actual generation of heat. This is particularly the case where the boiler equipment is supplemented by economizers or other means of utilizing the heat lost through high waste-gas temperatures. Owing, however, to the low specific heat of the gases, the heat loss due to high stack temperatures is not as great as is popularly supposed.

Low-grade fuel may be burned on grates in furnaces of special construction for each class of fuel, and special mechanical appliances (stokers and grates) are available for burning high-ash coal and lignite and also coke breeze.* It is probable, however, that low-grade coal and lignite can be utilized more advantageously in pulverized form. Lump coal burned on the grate in a hand-fired furnace, usually requires about 100 per cent of excess air, although with the best types of modern mechanical stokers this excess can be considerably reduced. With most kinds of pulverized fuel 25 or 30 per cent of excess air is sufficient, and, with proper attention, the amount needed may be even less. The resulting temperature of the fire is, of course, a limiting factor. Other factors having a bearing on this problem are the construction of the furnace, the proportion of heat radiated directly to the tubes, and the fusibility of the ash. Properly constructed furnaces and burners should be able to use any form of pulverized fuel which has sufficient carbon content. For the firing of steam locomotives, pulverized fuel offers a method which is worthy of serious consideration in all parts of the country where the use of oil is not more economical; in addition it furnishes a means of utilizing certain neglected solid fuels.

In the case of peat, and of bituminous coal rich in combined nitrogen, the value of ammonia as a fertilizer renders the by-product gas producer worthy of very careful consideration for large installations. The gas generated may be burned under boilers supplying steam turbines or it may be used directly in internal-combustion engines.

Comparatively little has been done in America in following

* On the utilization of coke breeze, see HAMOR, *Coal Age*, **11** (1917), 780.

this line of European development. Possibly the higher cost of machinery in this country has caused our engineers to look askance at a type of plant which requires a considerable initial investment. And, besides, the American farmer has not so far been adequately educated in regard to the advantages of fertilizer for the intensive cultivation of crops. Our chemists have, however, been endeavoring to awaken the nation to the importance of the nitrogen industry; and the generation of large amounts of power in hydro-electric plants has been advocated for the special purpose of making synthetic nitrogen compounds. Why not recover the nitrogen content of our fuels before burning them? Why not invest the capital required for hydro-electric developments in by-product gas producer plants for electrical power generation? It may be argued that the recovery of ammonia from recent and projected installations of by-product coke ovens will be sufficient. The saturation point for the use of fertilizers in America is, however, still far away.

ON THE UTILIZATION OF COAL-WASHER WASTE

It is clear that one of the chief fuel problems of the future is to be that of utilizing low-grade fuels, such as peat, lignite, mine-slack, bone-coal, and many other waste materials which, at the present time, are being discarded as too low in combustible matter to be of economic value. Some progress has been made in this direction in Europe, where the necessity of conserving fuel supplies has been felt more keenly than in the United States. Peat, in particular, has been exploited in England, Russia, and other European countries, and has come to be regarded as a rather important power fuel. Peat usually contains a high nitrogen content and it is for this reason that it has found such comparatively wide use. The nitrogen is recovered largely as ammonia where the peat is gasified in by-product producers, and consequently the gas is produced at low cost.

Coal-slack has also found some application in Europe as a fuel for by-product producer-gas manufacture, but, owing to its comparatively low nitrogen content, it has not been used widely for this purpose. It is claimed by certain gas manufacturers in England that low-grade coals containing as high as 40 to 50 per cent. of ash have been gasified successfully in by-product producer-gas plants. But the first cost of plant and the oper-

ating charges are considered to be too great for the economic utilization of such coals *per se* in this country within the near future.

The industrial use of high-ash fuels has, in fact, demanded much more attention in Europe than in the United States; but, so far as known, no special effort has been made to utilize bituminous coal washer-waste, or other similar waste materials, running 50 to 60 per cent, or more, of inert matter. The purpose of this section is to present the results of an investigation which has been carried out by Dr. C. B. Carter, under the direction of the authors, in an effort to devise a suitable method for the utilization of coal-washer waste, or refuse. Although this waste material inexceptively contains too little combustible matter to be of direct value as a fuel, it readily undergoes spontaneous combustion in the large dump piles accumulating at the washeries and accordingly becomes a nuisance. The object of the work conducted at the Mellon Institute of Industrial Research was to find an economic method of preventing or else abating this trouble. To this end, a number of possible uses for the material have been evolved, but in no case could serious consideration be given to these uses unless their practice would require a large daily consumption of raw material. The reason for this becomes evident when it is borne in mind that a big washery produces several hundred tons of refuse per day.

Flotation as a Method of Recovering the Coal Contained in Washer-waste.—It has been demonstrated at the Mellon Institute that the combustible matter contained in coal-washer waste of all grades can be recovered almost completely by suitable oil-flotation,* a concentration process which, as is well-known, is used widely on ores. Recoveries of 70 to 90 per cent of the total combustible matter present have been made at the Mellon Institute, the extent of the recovery being dependent upon the oil used, the size of the material, the degree of agitation, the method of grinding, etc. The ash content of the recovered coal has been found to depend upon several factors, such as the percentage of recovery, the method of grinding, etc.

If washer-waste is ground in such a way that the grains of coal are subjected to a rubbing or rolling action, the yield of recovered coal will be small and it will contain an excessive amount of ash. On the other hand, if it is crushed or ground in such a manner

* R. F. Bacon, United States Patent 1329493.

that the grains of coal are subjected to a minimum of this rubbing or rolling action, the recovery will be large and the recovered coal will be relatively free from ash. For the best results it has been found that the washer-waste should be *crushed* to pass a 48-mesh screen, the word crushed being here used in contradistinction to the word ground. The coal particles show the maximum floating properties when they are sharp, angular and lustrous. Grinding in machines of the disc-type destroys these physical properties, and the yield of recovered coal from refuse ground in this way is small and its ash content is high.

The amount of ash present in the recovered coal depends also upon the quantity of coal recovered. In general, it may be stated that the larger the recovery the greater will be the ash content of the recovered coal. If it is desired to increase the recovery from, say, 70 to 90 per cent, it is necessary materially to increase the agitation of the pulp in the flotation cell, and the ash in the concentrate will be increased, as a consequence, from 20 or 25 per cent to 30 or 35 per cent. This is doubtless due, in part, to the greater violence of agitation, but is attributable, perhaps in the main, to the fact that, even in the finely ground material, much of the coal is bound intimately to grains of slate which are carried over the walls of the flotation cell by virtue of the selective action of the coal for oils. With less violent agitation the buoyant action of air on the coal particles thus weighted down will not be great enough to carry them to the surface. Another factor which determines the ash content of the flotation concentrate, to a greater or less extent, is the percentage of pyrite in the washer-waste. Pyrite floats readily, and it is, therefore, evident that the ash in the recovered coal will increase or decrease proportionately as the pyritic content of the waste increases or decreases; it is probable, however, that this could be controlled by preferential flotation. In recovered coals showing 25 per cent of ash, from washer-waste containing 65 to 70 per cent of mineral matter, as much as 40 to 50 per cent. of the total ash is generally attributable to pyrite alone.

Conservative estimates (1917) show that a plant erected complete to handle 500 tons daily of ordinary bituminous coal washer-waste, and to recover the actual coal contained in it, will cost at a maximum $135,000; and a similar plant to handle 250 tons daily will not cost over $90,000. In the case of the first plant, it is computed that the coal can be obtained from 65 to 70

per cent ash refuse, to the extent of 75 per cent of the total coal present, in the form of *dry* 25 per cent ash concentrate, at a cost of $1.84 per ton. The same coal can be produced in the second plant at a cost of $2.00 per ton. If it is assumed that the recovered coal has a 32 per cent ash content, the recovery will be greater, and the cost of production becomes $1.45 per ton for the 500-ton plant and $1.58 per ton for the 250-ton plant. It must be emphasized that these estimates are only approximations, and it is quite probable that the actual costs of production would be much below the figures given. On the other hand, they are sufficiently reliable to indicate that it is doubtful whether oil flotation can be employed, at the present time, as an economic process for the recovery of the coal contained in such high-ash materials as washer-waste. The process is, however, also applicable to mine slack, bone-coal and certain other high-ash fuels which contain a higher percentage of combustible matter than the usual washer-waste of today, and undoubtedly this use will receive early consideration.

Although oil-flotation may not be an economic process for the recovery of the coal in certain low-grade fuels under present conditions, it will undoubtedly play a leading rôle in meeting prominent fuel problems of the future. The results of this research, therefore, constitute a reserve of knowledge until the time when it becomes necessary to utilize the various solid fuel wastes of the present.

Rewashing as a Method of Recovering the Coal Contained in Washer-waste.—It seems from the information at hand that intensive rewashing offers a satisfactory solution to the problem of recovering usable coal from accumulated waste. From the results of the above-mentioned inquiry, it appears quite probable that washer-waste of the type described can be rewashed by up-to-date washing machinery and that the final refuse will not be subject to spontaneous combustion, as it will contain 85 to 90 per cent of inert material. The combustible matter remaining in the final refuse will be integral with the slate and widely disseminated, and, for this reason, should not be affected greatly by weathering. The concentrate or rewash will contain most of the combustible matter in the form of 30 per cent ash coal and it is estimated that this rewash can be produced at a cost of about $0.20 per ton. It could be employed either directly as a fuel for boiler firing or admixed with low-ash coal as a fuel for by-product

producers. In the first-mentioned application it would be equal in heating value to bone-coal or mine slack of the same composition, and these fuels have been found to be quite satisfactory for boiler firing in plants where mechanical stokers are in use. In the latter case it probably would be necessary to mix it with an equal amount of good coal, in order to increase the nitrogen content to such a value that the recovery of ammonia would be profitable.

General Conclusions.—The most practicable solution of the problem of utilizing bituminous coal washer-waste economically therefore would seem to be to employ it as a fuel for the production of gas in a by-product producer gas plant. In order that it may be used for this purpose, the ash content would have to be decreased considerably and the nitrogen content increased. There are two methods of accomplishing this. A sufficient amount of good coal could be mixed with the refuse to reduce its ash content to 30 per cent, or less, and the nitrogen content would, at the same time, be raised to approximately 1 per cent. This method would demand a large unite plant capable of handling at least 1,500 tons of coal per day. The second method would require a plant of about 500 tons daily capacity. It would entail the rewashing of 600 tons of refuse, from which would be obtained 150 to 200 tons of rewash containing approximately 30 per cent of ash. By mixing this rewash with sufficient good coal to produce 500 tons of fuel, and then gasifying it in a by-product producer-gas plant, undoubtedly the waste material could be utilized economically.

Shallow Piling as a Means of Preventing Spontaneous Combustion.—A number of methods of coal storage have been described in the literature. As the result of a study of these methods, it is believed that shallow piling could be employed as a means of preventing spontaneous combustion in washer-waste bings. The method would require the distribution of the material over a large area, in layers not exceeding a few feet in depth. The first layer should be exposed to weathering conditions for several months before the second layer would be laid down; the second then should undergo exposure for several months, before the third would be deposited; etc., etc. The very rapid weathering in the shallow layers would obviate serious heating when the pile reached greater depths. It may be noted here that the subject of the spontaneous firing of coal requires more inquiry

from a fundamental standpoint; the entire process is essentially one of "surface combustion," but between the initial absorption of oxygen by the coal substance and its final expulsion in the products, water and carbon oxides, an entire series of complex phenomena may be involved. The points demanding experimental study have been indicated by Bone* and need not be mentioned here.

ON THE COMMERCIAL STATUS OF AMERICAN OIL-SHALES

It is extremely important that additional supplies of liquid fuel be obtained—a problem which essentially resolves itself into finding suitable substitutes for petroleum products. Indeed, it is certain that this fuel problem will come more and more into the foreground; and if in any way it were possible to provide a supply for only a small proportion of the liquid fuel consumed, it would be a most desirable attainment from the point of view of national economics.

Animal and vegetable oils are, of course, of too much value for a variety of other industrial purposes to find their way into the fuel market, where large quantities and low prices are essential. Wood and coal products—in particular, alcohol and benzene—can only be expected to relieve the motor fuel problem to a very limited extent; while peat oils do not give any indication of entering into the field in the near future, although the quantities of peat available in various parts of the world are sufficient to warrant some degree of local optimism.

Attention accordingly is being centered increasingly on shale oil—a crude petroleum-like oil obtained from bituminous shales ("oil-shales") by subjecting them to destructive distillation in special retorts. Shale oil has been found to be a satisfactory substitute for petroleum, affording similar results on refining, although with somewhat greater refining losses; but the output of the product in Scotland, the home of the shale oil industry and so far the only important producer, is not and never will be sufficiently large to make any serious impression on the fuel market.

Much publicity, a considerable part of which has been of a misinformative nature, has been accorded the enormous deposits of oil shales occurring in the Uintah Basin, which occupies the

* "Coal and Its Scientific Uses," 1918, 162.

northern portion of Utah, south of the Uintah Mountains and extending eastward into Colorado. Perhaps an even greater area of oil shales exists in a region of western Wyoming occupying the Green River Basin northward from the Uintah Mountains to Wind River Mountains. A third deposit of large size is contained 60 miles further east on the Colorado-Wyoming border. In addition, an area of approximately 2,500 square miles of oil shale has been located in the central part of Utah near Manti; while near Elko, Nevada, there occurs a small area upon which a number of locations have been made. Indeed, small areas of oil-shales up to 100 square miles in extent may be found in various localities all over the Rocky Mountain region. The deposits in the Uintah and Green River Basins are, however, the most notable and certain areas of them constitute reserves which are in readiness whenever it is deemed expedient to establish a great American industry to supplement the failing supply of petroleum from the oil-fields.

The oil shales of the United States so far have received comparatively little technical attention, mainly because petroleum has been abundant. It may be mentioned, however, that, prior to the establishment of a petroleum-refining industry in Pennsylvania, the Mormons destructively distilled shale for oil near Juab, Utah; that numerous attempts have been made in the past to distil cannel coal, and that some experimental work has been conducted on the Devonian black shale of the East. But no shale-oil industry has ever been established in America,* although various bituminous materials were distilled for the production of illuminating oil by a large number of "coal oil" companies about 1860. The process followed in this short-lived coal oil industry was very crude and ammonium sulphate production, found to be the necessary adjunct of the Scottish shale oil industry, was never attempted. Consequently, although a number of the coals and other substances used were of high grade, and merit investigation as to yield of crude oil, gas and ammonia according to present-day knowledge, it is not surprising that the refining of petroleum paralyzed the industry.†

* The oil shales of Canada are not discussed herein. For information regarding Canadian deposits and their importance, see especially ELLS and HAMOR, *Canada Dept. Mines, Report No.* **55**, Mines Branch, 1910.

† See BACON and HAMOR's "American Petroleum Industry," **1**, 203–212; **2**, 807–844.

The oil shale of the Green River formation in northwestern Colorado and northeastern Utah is to be regarded as a fuel resource of great economic importance—a reserve which should now receive broad research attention because the demand for petroleum and its products really exceeds the supply. The economic study of this shale was begun in 1913 by the United States Geological Survey, and the results of preliminary investigation demonstrated a promising yield of crude oil when the mineral was subjected to destructive distillation. More detailed examination along the north, east, and southeast sides of the Uintah Basin, in northwestern Colorado and in eastern Utah, has later indicated that, although the thickest and richest beds of oil-shale are exposed along the southern margin of the basin, nearly every section studied contains beds of shale more than 3 ft. thick which will yield petroleum-like oil. In fact, in Colorado alone it has been estimated by geologists that there is sufficient oil-shale, in beds that are 3 ft. or more thick and capable of affording more crude oil per ton than the average shale now mined in Scotland, to yield about 20,000,000,000 bbl. of crude oil, from which approximately 2,000,000,000 bbl. of gasoline might be obtained by the usual procedures in refinery practice. In Utah it is probable that there occurs an equal amount of oil shale, just as rich in oil-forming material, or kerogen.

It is important to mention here that oil shale cannot be worked profitably on a small scale and that the existence of a shale oil industry in this country can be assured only by the most rational treatment of a sufficiently kerogenous shale to give a satisfactory production of an easily refinable crude oil. Numerous field tests as well as the laboratory findings of the authors point to the fact that the quality of the crude oil yielded by certain of the oil-shales of Colorado and Utah compares rather unfavorably with that of the product obtained from the oil shale of the Lothians in Scotland; and it is also clear that, before any method for the distillation of oil from nitrogenous oil shale can be regarded as an efficient process, the desirable production of ammonium sulphate (*i.e.*, commercially satisfactory conversion of nitrogen into ammonia) must be secured. These problems can be solved in a suitable experimental-plant. The working of American shale will become as important an industry in this country as the distillation of carboniferous shale has become in Scotland, only after the manufacture has been based upon a

retorting procedure developed in a unit constructed primarily in accordance with the best experience.

Considerable preliminary investigation is accordingly essential. The particular object of such investigational work should be to ascertain the conditions for, as well as to determine the plant modifications necessary in, obtaining the maximum production of the best grade of crude oil in the retorts which are selected for development. The income resulting from the sale of the products of an additional stripping plant, namely, gasoline and fuel oil, might make such pioneer research work actually self-sustaining. Including the necessary condensers and tankage, and laboratory and shops, an experimental unit retorting plant having a throughput of, say, 100 tons per day would entail the expenditure of $500 to $1,500 per ton day, depending entirely upon the type of apparatus to be given trial. Its erection should immediately follow the demonstration of the continuity and uniformity of the seams through a desirable area; and it should not be enlarged to, say, a plant of 1,000 tons daily capacity until after the successful conclusion of extensive study.

Quite a number of processes have been proposed for the production of crude oil from American shales, but, until Jan. 1, 1921, none of the Western companies was producing in considerable quantities. A number of patents have been issued, but it is doubtful whether many of them possess any commercial importance; in fact, it is questionable whether any improvement or additions to previous knowledge are presented which would withstand legal consideration. To quote from a recent report:* "In the attempt to reduce the modest amount of labor required by the successful Scottish retorts, many mechanical monstrosities have been evolved whose operation would require a gang of mechanics and a heap of repair parts. Others exhibit the utmost ignorance not alone of distillation methods, but of furnace design and the principles of combustion and chemistry. It would seem that some company organized primarily to get shale oil would be well advised to erect Scottish retorts and adapt them to local conditions. These well-tried furnaces are mechanically good—they operate on recovered gas with a minimum of labor, make a good yield of satisfactory crude oil with an increasing amount of paraffin, and permit the recovery of large amounts of ammonium sulphate. Should labor-saving devices be considered essential,

* *Chem. Met. Eng.*, **20** (1919), 30.

the modern by-product coke oven with its marvelous mechanical equipment could be taken as a model, and so modified as to produce the regular temperature cycle needed for maximum yield."

The contention is not made in this Chapter that any type of Scottish dual-purpose retort* should constitute the actual basis for the development of an American shale oil industry, for this retort is not the design which is required today to handle most economically all grades of oil shale; but it is essential that more careful consideration be given to Scottish experience in retorting practice. This successful experience and the misfortunes of those who attempted to establish shale oil industries in Australia and New Zealand have demonstrated that the retort and its operation must be adapted to the specific shale to be retorted, and always with due regard to local industrial, financial, commercial and meteorologic conditions. The unmodified Pumpheston retort was a failure when used in Australia because it was totally unsuited for dealing with the richly kerogenous, yet non-nitrogenous, shale of New South Wales; whereas the oil shales of Scotland are generally low in yield of oil and relatively high in yield of ammonia, when destructively distilled in the same type of retort. It is therefore unsurprising that a large amount of money was lost in this attempt to obviate experimental work by adopting a retort which was very successful on a totally different variety of oil shale under entirely dissimilar economic conditions. American oil shales are comparatively rich in characteristic† kerogens,[1] but in the Western States they are generally low in nitrogen-content, while in New Brunswick, for instance, the oil shale is highly nitrogenous, although it yields an oil which is inferior to the Scottish. In fact, almost every condition to be encountered on this continent differs materially from the conditions which have been responsible for the Scottish dual-purpose retort.‡

* SIMPSON (*Chem. Met. Eng.*, **20** (1919), 204) employs this term to illustrate the fundamental object of Scottish practice, *viz.*, the production of crude oil and ammonia in one retort.

† On American oil-shales, see BASKERVILLE and HAMOR, *J. Ind. Eng. Chem.*, **1** (1909), 507; *Orig. Com. Eighth Internat. Cong. Appl. Chem.*, **25**, 631; ELLS and HAMOR, *loc. cit;* and U. S. Geol. Surv., *Bull.*, **581**–A and **641**–F. See also the monograph on "Shale-Oil" edited by R. H. MCKEE. Published by the Chemical Catalog Co., N. Y., for the American Chemical Society.

‡ On the principal factors involved in Scottish shale-oil technology, see BACON and HAMOR, *lib. cit.*, **2**, 807 *et seq.*

A complete Henderson retort, one of the Scottish types, was erected by the Southern Pacific Railroad at Elko, Nev.; but it is understood that the experimental work was discontinued early. With adequate financial support and technical supervision, this attempt to adapt Broxburn practice to an American deposit should have resulted in the accumulation of valuable information. It may be noted here that some twenty semi-commercial and experimental plants of various types have been built, but none of these has developed to the point of marketing any of its product. In fact, it is doubtful whether more than 200 bbl. of crude shale oil were produced up to Jan. 1, 1921, from western oil shale. Much of the oil shale agitation is unfortunately company publicity and it is clear that proper development is impossible as long as the stock promoter remains the prominent feature of the situation. The successful exploitation of our oil-shale reserves will require careful investigation on the part of a competent technical staff. For the assurance of successful large-scale operation, a retorting process must be used which will give good yields of economically refinable crude oil and, wherever commercially possible, of ammonia; easy methods must be perfected to separate the unstable compounds from the products of the crude oil, and the market must be educated to absorb the finished products of the refinery.

SOME SPECIFIC ENGINEERING PROBLEMS IN THE UTILIZATION OF FUELS

From an industrial engineering standpoint, the problems arising in connection with fuels and their use are various indeed. However, the operating engineer is concerned chiefly with the many difficulties encountered in securing perfect combustion; the proportioning of boiler heating surfaces, combustion spaces, and grate areas; flue-gas baffling within the boiler for utilizing the maximum amount of heat; and clinkering.

Examining the entire subject of the utilization of fuels in its varied engineering aspects, it is found that the conditions of firing present an array of frequently encountered problems. In the case of coal, there are found: the type of stoker as influenced by the character of the fuel; the provision of draft; the control of flue gas; flame properties; crushing and sizing; reduction of flue-gas temperatures; air leakages through settings; radiation on conduction of heat through settings; design of combustion

space for perfect burning; furnace refractories; clinkering and ash disposal, and storage.

While engineers generally have agreed as to the draft requirements and grate areas for various kinds of fuel, no definite data are available regarding the furnace volumes required and the rates of combustion for various types of fuel. What are the effects of purely meteorological conditions on the natural draught of a chimney? How can we most economically ensure proper and complete combustion of coal on boiler grates and elimination of losses due to improper firing? How can we minimize heat losses due to scale, flue dust and improper boiler settings? A practical method of heating material with less unused space in furnaces is also an appropriate subject for research. The determination of reasonable specifications for Kentucky, Tennessee and other coals and cokes requires consideration. What is the best method of burning efficiently low-grade coals which clinker badly? What is the most suitable method of burning high-sulphur coal without clinker or fusion? Research attention should be accorded the development of a satisfactory furnace-lining for high-sulphur fuels. How can peat and lignite best be used in rotary furnaces, such as dryers and kilns? What is the most efficient type of automatic grate for burning screenings or slack coal? Successful automatic stokers are wanted for burning low-grade anthracite fuel. Inquiry has also been made for a relatively inexpensive, simple, mechanical stoker which will be suitable for installation under process furnaces where the consumption of coal is limited. And, then, what is the most satisfactory means for burning coal and wood refuse in combination?

In modern designs of steam power plants it is not possible to convert over 13 per cent of the total heat value of the coal into steam power. This condition has been long discussed, and designs of stoking machinery, smoke consumers and other devices intended to decrease this great loss are numerous. To find the remedy the preventable part of this loss of fuel, it appears to be in line that before we can successfully construct apparatus to handle fuel and obtain the greatest evolution of heat, it is first essential to standardize a raw fuel by concentrating it into a fuel of homogeneous structure. This may be accomplished by coking and briquetting processes, each of which has its special advantages. The manufacture of artificial fuels or briquets is a

field in which great advancement can be made, for it enables a number of lower-grade fuels to be mixed with those of more desirable properties and consolidated into a fuel which may be moved without breakage and at a minimum transportation cost. Fuel briquetting in America has not met with the success up to this time which it rightfully deserves, although, of course, certain of the difficulties have grown out of the inexperience of the operators as well as the fact that a number of the plants have not had adequate financial support.

Some of the problems in coal carbonization are listed below. Considerable research attention is being accorded to this subject at the present time, both in England and in United States; the technical progress which has been made recently is presented on page 417.

1. The obtaining of data of unquestionable accuracy for the preparation of thermal balance sheets for various methods of coal carbonization and the gasification of coke, and in connection with the use of gaseous fuels in industrial furnaces.

2. The obtaining of data for the preparation of economic balance sheets for carbonization, gasification and furnacing operations.

3. The obtaining of similar thermal and economic data in connection with the use of peat as fuel.

4. Experimental work on carbonization at temperatures up to 650°C. and on various types of apparatus for this purpose.

5. The study of the coke produced under (4) from various types of coal as a smokeless fuel for domestic and industrial purposes, either directly or in the form of briquets.

6. The study of the oils produced under (4) as a source of fuel oils for use by the navy in steam boilers or in Diesel engines.

7. The study of the hydrocarbon gas produced under (4) with a view to its utilization directly as a high-grade fuel or as a source of fuel alcohol.

8. Experimental work on carbonization in continuous vertical retorts with and without steaming, and the study of the thermal aspects of these operations.

9. Experiments on the carbonization of coal at high temperatures to ascertain the influence of temperature, and of the rate of heating, on the quality of the coke produced, and on the

yield of by-products, with a view to the possible utilization of low-grade coking coals for the manufacture of metallurgical coke.

The development work done in combustion through the use of stokers, in combination with under-grate blowers and retorts, has about exhausted the possibilities in this direction, and a radical departure from the existing practice is necessary in order to utilize to the fullest possible extent the thermal energy of fuel. The use of fuel in pulverized form offers a basis for further development work in this connection.

With pulverized coal, we have the problems of crushing and drying, explosibility and storage, injection into the firebox, and refractory erosion. In particular, the most economical method of storing and handling pulverized coal with boilers requires more exhaustive investigation. Easily cleaned regenerators for furnaces using pulverized coal are desired. And, finally, what is the relative value on a heat and cost basis of pulverized coal, fuel oil and producer gas?

Scientific smoke inspection, together with improved furnaces and fireplaces, has done and will do much to abate the much discussed smoke nuisance, but smoke will never be finally abolished so long as raw bituminous coal in its present form is used as a fuel. While the use of mechanical stokers will assist along this line, the hope of eventually effecting the abolition of the evil lies principally in three general directions. The first is a wider extension of the use of gaseous and powdered fuels for heating purposes, and researchs having for their purpose the increment of the efficiency of gaseous combustion, or the improvement of the use of pulverized coal and the generation and application of gas for fuel purposes, are enacting contributory rôles of importance. The second is the adoption, along very broad lines, of electricity as a motive power. The third lies in the trend of manufacturing some form of semi-carbonized coal as a smokeless domestic fuel at a price which will not exceed that of raw coal, and this problem now is receiving serious investigation, especially in Canada and England.

In the case of gas fuels, there are the important problems of the improvement of burners and methods of air-mixing. In producer-gas technology, not much trouble is reported with mechanical-type producers; but with the fixed-type, clinkering, incomplete burning of coal, air-holes and pressure have been

causes of complaint. What is the most economical size and shape of producers for gas to be used for heating purposes? The economic utilization of the tar by-product from producers requires more study; and engineers request research on the automatic, separate control of the steam and air blasts in producers, and a practical automatic check and regulation to maintain the uniform quality of producer gas. A large steel company has been investigating the problem of making a washed by-product gas luminous on burning. But perhaps the greatest need in gaseous fuels is obtaining a cheap fuel gas from a central station large enough to conduct profitable by-product recovery.

With fuel oil, there are the problems of explosibility, storage, burning for perfect combustion, and action on furnace refractories. Insufficient and improperly adapted oil burners have caused expensive difficulties in burning oil. Some trouble still is experienced in burning heavy asphalt-base fuel oil; and burners clog occasionally, even with light fuel oils. Localized heat renders the use of fuel oil less desirable than washed producer gas, according to some engineers. The combustion of fuel oil to secure good heat regulation where different temperatures are required at various stages of the operation of chemical apparatus, and the use of fuel oil instead of coal for steaming and open-evaporating, with relative costs, are problems of chemical industry. There are also inquiries regarding a widely applicable method of utilizing waste heat from oil and gas-fired apparatus, more efficient oil and gas burners, and a simple and efficient combination gas and oil burner.

The most potent factors in the conservation of fuel during the last twenty years have been: (1) the development of water power, (2) the concentration of the production of power from fuel in central stations where the most economical methods may be utilized, and (3) the distribution of power electrically. There is still much to be done in the way of replacing inefficient isolated power plants of various kinds and sizes with electric power. From the point of view of fuel conservation the most important field remaining for the most extended use of electricity is on the railways. One-fourth of all the coal mined in the country, as well as a considerable quantity of oil, is consumed by steam locomotives. The locomotive is an isolated power plant of but medium efficiency, and the only excuse for its continued existence is the cost of electrification.

FUEL PROBLEMS IN THE REFRACTORIES INDUSTRY

The fuel difficulties encountered in the burning of refractories divide themselves into two classes, one of which deals with the efficient use of the heat units developed and the other relates to the securing of heat.

When heat balances are made of kilns they show that from 8 to 12 per cent of the heat is used to develop the ware, *i.e.*, to expel moisture, complete the chemical reactions which may take place, and thoroughly shrink the refractory article. From 40 to 75 per cent of the heat is lost to the kiln itself, in heating it and by radiation. From 10 to 25 per cent of the heat is carried out by the hot stack gases. These difficulties are overcome largely by the use of continuous kilns, whereby the fuel requirement is decreased from 1,950 lb. to 700 or 750 lb. per thousand brick. There are three problems of this general nature, *viz.*:

1. Decreasing radiation loss;
2. Decreasing stack losses; and
3. Decreasing kiln loss.

However, the most important problems pertain to the development of the heat.

1. The heat must not be too intense at any one point or some ware will be burned unnecessarily well and other ware will require to be reburned.

2. There is the problem of conveying producer gas from a central plant to the various kilns without losing a great amount of heat, *i.e.*, by the cooling of the gas.

3. The pulverized fuel problems consist in the prevention of the deposition of ash-dust and in developing a feeder which will work slowly at low temperatures and yet give combustion. This feeder must be a unit in itself, since, because of the fact that the kilns are round, one can not have a central shaft as a source of power.

4. A fourth problem is that of securing good draft at all times. When the air is "muggy," the temperature increase is very slow and often the kiln can not be finished properly. By using "artificial draft," secured by fans, it may be overcome.

5. In the fireboxes the tendency is to clinker. At the lower temperatures these boxes must be "cleaned" after about the fourth day. The full heat then is applied and the boxes must be cleaned every 6 to 12 hr., depending upon the fuel. Every time

they are cleaned the fire practically goes out, cold air rushes in and the kilns fall from 50 to 200° in temperature. This problem resolves itself into the provision of suitable draft as well as fuel, but is caused mostly by the clinkering of the coal used.

6. A minor problem arises from the tendency of the ashes to fall on the brick and remain on them. This troublesome deposition may spoil 500 to 2,000 brick in a kiln. As a rule, old bricks are put in these ash-collecting positions, and are used over and over again.

FUEL PROBLEMS IN THE GLASS INDUSTRY

In the glass industry the problems related to fuels may be divided into two groups, *viz.*, economic and engineering problems.

Economic Problems.—The first requirement for the glass factory is that the supply of fuel shall be continuous. This is obvious since the fire is maintained in the furnaces for 11 and sometimes for 18 to 24 months. The fact that an interruption in the supply of fuel may necessitate a virtual rebuilding of the furnace illustrates the need for a continuous supply of fuel. The second requirement is a fuel of low cost. The cost of fuel averages approximately the same as the cost of the raw materials of which the glass is made and comprises about 10 per cent of the total manufacturing cost of the glass.

Natural gas has fulfilled both of these requirements to an admirable degree; but since the price has risen above $0.20 per 1,000 cu. ft. and especially since the supply is becoming inadequate and intermittent in certain localities, the glass industry is facing the economic problem of a new source of fuel. Fuel oil has been used as an emergency fuel, but it is too expensive for general use. Coal is therefore considered, from the economic standpoint, as the most suitable source of fuel since it satisfies both of the conditions noted above. It should be mentioned, however, that experiments are in progress on the use of electrical energy for melting glass, as well as for heating the annealing leers and kilns. The possibility of utilizing electricity in glass-making opens up a large field, with many problems both of an engineering and economic nature.

Engineering Problems.—The application of oil as a fuel involves practically the same engineering considerations as that of gaseous fuels. Mechanically and thermally it is an entirely satisfactory fuel. Coal is sometimes burned directly in the pot

type of furnace, but this is inefficient and is not the usual practice. It is not applicable for tank furnaces, and the transformation of coal into producer gas is therefore the most general and efficient manner of using coal in the glass industry. Improvements in the design of producers and the application of the lower grades of coal offer opportunities for the betterment of the glass industry. Powdered coal has been in experiment for melting glass, but has not been successful because of the ash and other impurities which contaminate the glass and choke up the flues. A successful elimination of these factors would go far towards fuel economy in glass making. Powdered coal is, perhaps, applicable to pot furnaces and to the newer types of muffle annealing leers and kilns, but some form of gaseous fuel would be necessary for the "glory holes," the "fire polishing" flame, and the small "cracking off" and melting flames employed in finishing certain kinds of glassware.

One of the most important problems in the glass industry is that of heat economy. Glass furnaces are notoriously wasteful of fuel. Accurate measurements of the heat balance of glass furnaces are few, but it has been shown in the case of a plate-glass furnace that of the total heat supplied only 17 per cent was required to melt the glass, while 56 per cent was lost through radiation and conduction and in the chimney gases. Even in some of the modern tank furnaces the loss of heat is increased deliberately by air blasts against the outer walls of the furnace.

The application of the fuel to the furnace is crude in the sense that the present practice is to a large extent the result of empirical methods. Scientific research in the standardization of furnaces; in the determination of the most efficient number, size and position of the ports, in the arrangement of the baffles, in regulating the air supply and the gas pressure, and in the most efficient construction of the regenerators, will, without question, effect marked economies in the amount of fuel required in the glass industry. The furnaces used for melting glass in closed pots are far less efficient, thermally, than tank furnaces. Owing to the arrangement of the pots (they rest upon a solid brick hearth and are placed close together and close to the furnace wall), the heat for melting the glass must be conducted or radiated through only the top and back walls of the pot. A furnace designed to heat the pots evenly on all sides would greatly reduce the heat loss in this thermally inefficient type of

furnace. There is need for a more uniformly heated leer and for more accurate regulation of leer temperatures. Such control would result in more uniform annealing and less subsequent breakage, and would in many cases eliminate the necessity for a second annealing in the kiln. The same remarks might apply to the annealing and decorating kilns, which probably could be replaced by a really efficient continuous leer.

Thus, the problems of fuel in the glass industry are also closely related to those of refractories, of furnace design, and of pyrometry; and improvements in the materials and the design of the furnace and of the scientific methods of control will assist materially in reducing the amount of fuel at present wasted.

FUEL PROBLEMS IN THE IRON AND STEEL INDUSTRY

The economic manufacture of iron and steel is dependent not only upon the raw materials available, but also on the judicious combination of their utilization and the recovery of all by-products. It is probable that the greatest fundamental error has been made by considering fuels in their relation to metallurgy alone and by not regarding them in a two-fold aspect rather than a single one. To illustrate, in the smelting of iron we have first the coke-oven, which yields not only the metallurgical fuel, but also a gas which is extremely useful for domestic purposes, and then, too, ammonia is produced. In the utilization of the so-called waste gases of the blast furnace there is presented a fuel which is available for the production of energy on an enormous scale, and this energy must, in many cases, be sold to outside parties if it is to be used. Because of collateral matters of this nature, it is necessary, in the treatment of the fuel problems arising in the iron and steel industry, to take a comprehensive view.

Everything is concentrated that goes into the furnace (ore, coke, fluxes, etc.), except the oxygen of the air, which is added with four times its volume of inert nitrogen. If more concentrated air or even pure oxygen could be used, a great saving could be effected, and there could be done in combustion furnaces much which is now only possible in electric furnaces. This problem has been discussed frequently, but comparatively little research has been devoted to it.

The problem of sulphur is one of the most important in iron metallurgy. Sulphur is one of the most deleterious elements

required in the manufacture of steel. Reference is had to some which can be present in iron, and, while it can be kept out, notwithstanding the high affinity of iron for it, the procedure is expensive. When charcoal is used as a blast furnace fuel, only about four-fifths as much of it is required to make a ton of iron as when coke is burned, although the fixed carbon in charcoal is equivalent to but 75 per cent. of that contained in coke. The same considerations are applicable in the conversion of iron into steel. To keep the sulphur content to a minimum is increasingly difficult as the amount of sulphur in the fuel becomes higher. The ash problem is next in importance. The disadvantages which arise from ash are very great because of the increasing slag volume and the difficult character of the slags frequently produced.

Another group of serious problems in iron metallurgy relates to the closely allied by-product coke industry. An important problem is the reduction in cost of plant. The large amount of capital invested for even a small sized by-product coke oven plant is such as to deter many who would otherwise be willing to install by-product coke ovens. There is no doubt that much can be done toward decreasing this cost by simplifying the means of operation and possibly by the use of less expensive materials of construction. There are also possibilities in the way of improving the heating of the coke ovens. Much has already been accomplished in this direction, for it is only a few years ago that by-product coke ovens were making practically no surplus gas, whereas records from recently constructed plants show as much as 62 per cent surplus gas. The importance of any scheme for further reducing the amount of fuel required for coking the coal depends, of course, upon the value of the heat units saved in any particular locality. Another problem relates to the improvement of the refractory materials used in by-product coke oven construction. Much has been accomplished by the substitution of silica brick for the old firebrick, and, if there were available a succedaneum of silica brick that would make a proportional improvement, the advantages to the industry would be very great. Possibilities have also been considered in the way of making the coking process a continuous operation, and, finally, there is a great field for improvement in the recovery and utilization of the by-products.

One of the greatest needs of all industrial life is particularly

method of gas production which will enable the gasification of coal with high efficiency and with the product possessing a calorific value of not less than 500 B.t.u. per cubic foot.

It has been maintained that tar-oil can advantageously replace coal in many instances for the heating of open hearth and other furnaces in which a regular temperature and neutral atmosphere are required. Certainly this replacement requires the consideration of research. The question of the recovery of the whole of the gas from coke ovens is a problem which is encountered by all builders in new installations. If ordinary producer gas is employed for heating the coke ovens, and advantage is taken of double regenerators to heat up both this gas and the air supply, it is claimed that all the gas from the ovens will be recovered. The application of approved types of producers adapted to low-grade fuel is another problem; it is contended by some engineers that these should be used exclusively, and, of course, in large installations recovery of the by-products from the producers can be taken into account.

CHAPTER XXVI

THE PROBLEMS OF THE PETROLEUM INDUSTRY

By

William A. Hamor

Benjamin Silliman, Jr., who conducted the first technochemical investigation of crude petroleum, in 1855, remarked that it was a raw material from which might be manufactured very valuable products. With an industrial history covering a period of but 60 years, crude petroleum now is recognized as a resource of the highest economic value to society because it is essential to agriculture, manufacturing, commerce and the pleasures of life. It is the source of gasoline, which is responsible for the development of the internal-combustion engine, the increase of the use of which has strengthened the entire aspect of modern civilization; it gives the world its supply of illuminating oils, which, by bringing a cheap light to millions of people, have constituted America's greatest gift to the uncultured peoples of the globe; and it provides the lubricating oils upon which the complex mechanical equipment of today is dependent for its operation. Then, too, part of the industrial activity of our country rests upon another petroleum product, fuel oil, which also is required for the operations of an oil-burning navy.* The fact that crude petroleum forms the basis for a chemical products industry of almost unlimited possibilities of development, and as distinctive as the coal tar industry of the present, brings out, in addition, its predominant importance among mineral raw materials.

A substitute has been found for crude petroleum, but shale-oil, to which reference is had, is a chemical product and therefore is subject to economic limitations not applicable to a substance which may be mined and handled so easily as crude petroleum. Indeed, the availability and magnitude of the petroleum resource

* Forty-eight per cent of the power used by the British Navy in the European war was derived from petroleum and the fleet steamed 7,000,000 miles per month. In 1918, 3,000,000 tons of fuel oil were shipped from the United States to the Allied navies.

have given confidence for the extensive mechanical developments essential to its use; and accordingly the employment of petroleum is established among the practices and requirements of modern life. As pointed out by Gilbert and Pogue,*

> Any tendency toward disuse of its essential products, either through undue increase in price or from decline in production, will mark a turning point in material comfort and industrial advantage, the deferring of which becomes an object of universal concern. As the petroleum deposits of the United States have been drawn upon with extraordinary rapidity and the supplies have already suffered serious depletion, the matter of their approaching exhaustion assumes the light of immediate importance. The comforting assertion that such considerations may be safely left to future generations does not apply to petroleum.

Crude petroleum now is being taken from the ground in the United States at a rate approaching 400,000,000 bbl. per annum. This is five times the rate in 1901 and twice that of 1909.† At the close of 1919 approximately 4,986,300,000 bbl. of crude oil has been produced in this country since the first well was drilled at Titusville, Pa., in 1859. This is about 43 per cent of the original recoverable content, as estimated by the United States Geological Survey. All this oil that has been mined in the United States in 60 years would be taken out in 13 years at the present rate of production. Impressive as this fact may be, it is not so disturbing as the realization that the recoverable crude petroleum in this country, according to the conservative estimate, would probably be practically exhausted in 17 years if the 1919 rate (nearly 380,000,000 bbl.) of production could be maintained for so long, while a reserve of 7,000,000,000 bbl., the moderately liberal estimate, would disappear in 18½ years.‡ If an improbable excess of 2,500,000,000 bbl. over the estimated amount is present, this excess would be sufficient to sustain the present draft for 6½ years additional.

What improvements will in the next 10 years be made in the process of extraction of crude oil from the ground, and what the effects may be in recovering the great amounts of crude petroleum not "available" or recoverable by present methods, remain to be seen. It is probable that not much over 20 per cent of the oil underground is brought to the surface. It is most important

* U. S. Nat. Museum, *Bull.* 102, I, **2**, p. 29.

† See "World's Production of Petroleum," U. S. Geol. Sur., Jan. 22, **1920.**

‡ Dr. David White, of the U. S. Geol. Sur., has furnished these data.

that studious attention be given to the problem of the more complete extraction of the petroleum than is possible by the methods now in general use. Records of wells should be kept, surface and underground geology should be correlated, oil sands should be examined, and, if possible, underground losses should be determined. The estimated available supply should be increased in this way to the maximum. It is noteworthy that, while the petroleum industry has been supplied with technical means whereby certain wastes in production may be combatted, there has been provided no adequate machinery for applying this knowledge.

Fortunately the crude petroleum cannot so soon be taken from the ground. Even unparalleled prices for crude oil, and exploratory work far more extensive than that now in progress, cannot within the next generation disclose all the oil pools in the strata; and although devices for more rapid extraction may be invented and applied, the fields which remain to be discovered cannot be drained so rapidly. Oil pools will be found, finally by accident, long after the search has waned, and even in the next century. These are some of the reasons why the production of natural petroleum in the United States must pass its peak at an early date—probably within 5 years and possibly within 3 years—while the long sagging production curve may be carried beyond the century. It is certain that this country must in the near future lose its supremacy in the petroleum world and become more and more dependent on the oil resources of other lands,* except in so far as the situation may be saved by the successful production of artificial petroleum (crude shale-oil) by the destructive distillation of American oil shales.

To depend on oil shale, however, is to trust to uncertainties both as to costs and as to ultimate results, and is at best to superimpose on our present social and industrial fabric an enormous and complex new industry rivaling in part our coal-mining, salvaging but a part of our present petroleum industry, and requiring many years for its development. If the quantity of coal mined in the United States during any recent year were all oil shale, of average crude oil yield, the amount of artificial petroleum producible therefrom would not equal the natural

* On the restrictions imposed by certain foreign countries upon citizens of the United States in prospecting for or acquiring lands containing petroleum, see *Senate Document* **272**, May 17, 1920.

petroleum produced for that year. Sooner or later—perhaps within 5 years—a commercial shale-oil industry may be born in this country, but that it can originate soon enough or become large enough to offer any considerable contribution before our domestic petroleum production is already on the wane seems improbable. Finally, if shale oil yielding the principal and indispensable petroleum products cannot be produced successfully and marketed as cheaply as natural petroleum from other countries, the public cannot be expected to build up and sustain a shale oil industry, unless it be under subsidy as a protective measure.

To date approximately 150 shale oil companies, many of which claim to own or control novel distillation processes, have been formed in the Western oil shale fields; but so far none of these organizations has assumed a position of commercial importance. However, research of a fundamental character is being carried out by various large petroleum interests and by the Bureau of Mines. It is hoped that the Bureau of Mines will serve the useful function of investigating new types of retorts and of determining the most profitable use and method of treatment of any particular oil-shale. This valuable pioneering work would bear fruit ultimately in the production of a notable volume of shale oil.

A British oil economist has calculated that by 1925 the petroleum requirements of the United States will exceed 500,000,000 bbl., and that at a later date our country will become more and more dependent upon British supplies. An American authority, W. C. Teagle, president of the Standard Oil Co. of New Jersey, has estimated that in 1925 the requirements of the petroleum industry in this country will approximate 650,000,000 bbl., an increase of more than 220,000,000 bbl. over the requirements of 1919. Unless conservation of petroleum through curtailment of use—for example, as fuel burned under steam boilers to generate steam—is forced automatically by the scarcity of crude oil and consequent prohibitive prices, or is sooner and more wisely brought about artificially by regulation, it seems probable that the demands of the American petroleum industry will considerably exceed 600,000,000 bbl. or possibly 650,000,000, as estimated by Teagle, in 1925, although by that time our exportation of refined oils to some of the foreign markets will probably be

reduced by the competition of foreign oils nearer at hand and more cheaply produced.

A drain of over 500,000,000 bbl., even if the yearly effectual demand be not further increased, would, if taken from the oil fields of the United States, probably exhaust the petroleum resources remaining available in the ground in 14 years, or in 16 years if it is assumed that the recoverable petroleum possibly amounts to so much as 8,000,000,000 bbl., which seems very improbable to geologists. It is fortunate for the country that the petroleum cannot be extracted so rapidly. On the other hand, it also seems quite improbable that an annual production of natural petroleum amounting to so much as 450,000,000 bbl. can be won in any year from our domestic oil fields, the peak of whose production is likely to be passed by 1925.

All circumstances being considered, it must be expected therefore that, unless our consumption is checked, by 1925 the United States will be dependent on foreign oil fields to the extent of 150,000,000 bbl., and possibly as much as 200,000,000 bbl. of crude oil each year, except in so far as the situation may by that time, perhaps, be helped to a slight extent by shale-oil. Add to this probability the other greater probability that within 5 years—perhaps 3 years only—our domestic production will begin to fall off, with increasing rapidity, due to the exhaustion of our reserves, and it becomes evident that, except for such relief as may come from shale oil production, the future of the United States in petroleum will yearly become more and more completely dependent on supplies to be brought from foreign fields.*

As the outlook now must be viewed, it is practically certain that after a time the United States will be buying petroleum from commercial rivals in quantities greater by far than ever have been sold to them, to make no mention of the prices paid. But, while this may be impreventable, it should be escaped as far as possible. If our nation is to have these oils as cheaply as they are sold in the

* United States interests are practically supreme in the commercial control of the petroleum resources of the Western Hemisphere, dominating the petroleum industry in the United States, Canada, Mexico and Peru, and holding substantial interests in Trinidad and Venezuela and in the prospective petroliferous areas in Central America and Colombia. Their only competitors are British and British-Dutch interests, which control the petroleum situation in Trinidad and are not only strongly intrenched in Mexico and Venezuela but are seeking aggressively to enlarge their holdings in those countries and to gain footholds elsewhere.

home countries; if our industries, our transportation, our navy and our standards of living are to be safeguarded in advantages as great as those of our rivals, and if our merchant ships are to obtain their fuel oil at prices as low as those paid by rival ships, the oil supplies needed must be in our control. Our prosperity and our prospects, so far as they may be affected by this important commodity which influences the daily life of every citizen, must not be subject to prejudicial regulation or discriminative restriction by any foreign power. Only by assuring American control over the petroleum supplies required by the United States can the protection of our future be guaranteed.

Experts believe that the most conspicuous developments affecting the sources of the world's supply of petroleum in the next decade will occur in the countries that border the Caribbean Sea and the Gulf of Mexico. Within the last 4 years the annual production of petroleum in Mexico has increased from 21,000,000 to 56,000,000 bbl.* and the potentialities of future production in that country have been demonstrated. It is estimated by T. C. Thomson† that the ultimate expected production will equal, if not surpass, the whole production of the United States. Its product, originally considered valuable only as a source of fuel oil, now is yielding, by modern refining methods, increasingly important percentages of illuminating oils and gasoline. The hindrances to enormously increased production are unsettled political conditions and inadequate facilities for marine transportation, but these obstacles doubtless will be surmounted within the next few years.

To summarize, the future domestic supply of crude petroleum will not be equal to the future home demands. This problem can be met by:

1. Obtaining greater supplies of crude oil—
 (*a*) By increasing the importations from foreign oil fields.
 (*b*) By actively participating in the development of foreign oil fields.
 (*c*) By the establishment of industries manufacturing substitute petroleum by the destructive distillation of oil shale, coal, etc., as soon as is practicable.
 (*d*) Through increased recovery from our oil fields, resulting

* In the same period our imports of Mexican crude petroleum have increased from 15,175,061 to 45,893,945 bbl.

† *J. Inst. Pet. Tech.*, **5**, 56 (1919).

from more efficient operating methods, and especially the elimination of wastes in production.

2. A better utilization of the crude now available, principally—
 (*a*) By the pyrolysis of fuel oils into gasoline.
 (*b*) By the development of gasoline substitutes.
 (*c*) Through the development and use of Diesel-type engines utilizing the heavier fuel oils.

PROBLEMS IN THE PRODUCTION OF CRUDE PETROLEUM

Among the development and production problems which require more study are the dehydration of emulsified petroleum and the prevention of its formation in oil wells. It has been learned that probably all emulsions in wells are formed after the oil has left the sand, and their formation often can be prevented. The systematic investigation of methods for excluding water from oil and gas wells, of the effect of water on the production of oil wells, and of casing and tubing problems, would lead to findings of technical value. Work on the employment of safety devices in the oil fields, the possible substitution of explosives safer than nitroglycerin for shooting oil wells, and the effects of shooting on wells, would be of utility. Scientific inquiries for determining the capacities and characteristics of oil and gas sands, the proportions of petroleum not being recovered by present methods of production, and the laws governing the expulsion of petroleum from the oil sands have been started by our energetic Bureau of Mines. There is little information on these subjects, and it will not be possible to interpret data and to judge the value of various methods of production until the underlying geochemical laws are better understood. Procedures for stimulating production and increasing the recoveries of petroleum from the sands, including the effects of vacuum pumping, use of compressed air or gas, and use of water flooding, present other opportunities for research. In this connection, pumping problems and equipment, including the use of automatic air and gas pumps, electrical equipment, and air lifts, should be given attention.

Storage and transportation problems include losses of oil in storage, prevention of fires at tanks and wells,* the flow of oils in pipe lines, and the construction of storage tanks and reservoirs.

* On oil fire hazards, see U. S. Bureau of Mines, *Bull.* **170.**

SOME PROBLEMS IN REFINERY TECHNOLOGY

Petroleum industrialists frequently have availed themselves of the service of scientific research,* both in the development of processes and in the perfecting of the necessary mechanical equipment. In fact, marked success has attended scientific progress in the refining of petroleum, and the largest refineries now concede that chemistry is the source of specific information for the petroleum industry and gratefully acknowledge that the efficiency of their plants has resulted largely from properly conducted scientific investigation. Those companies which stand well to the fore maintain one or more research laboratories, and industrial research has left its mark on their development. It is, however, essential, particularly for the future welfare of the industry, that there be an increment in investigational activity. This may be brought about in a measure by the organizations represented in the petroleum industry, especially the American Petroleum Institute, and by the Bureau of Mines; but there must be more cooperation between petroleum industrialists and the universities and scientific societies if the desirable fruitful research is to be stimulated. The Petroleum Section of the American Chemical Society is encouraging scientific inquiries in hydrocarbon chemistry and naphthology.

The need of continuous study and research and training in hydrocarbon chemistry and in petroleum technology cannot be over-emphasized.† The lack of reliable general information has worked handicaps on the petroleum industry, which is, in many ways, groping in the dark. Similar errors are made repeatedly in the same territory by different operators, and both in drilling and in refining the various factors having a known influence are understood imperfectly in their relation one to another. Geol-

* A good illustration of what research has done in working out refining problems is had in the case of liquid petrolatum. At the beginning of the war a great shortage of this product occurred, since its manufacture had been carried on solely by the Germans from Russian petroleum stock, which was thought to be the only suitable basis. After scientific inquiry, the manufacture of liquid petrolatum was begun on American oils, and the present American product is superior to the old German "paraffinum liquidum" in a number of respects.

† It is gratifying to note, however, that at least one American institution now is supplying trained petroleum chemists to the industry. Reference is had to the University of Oklahoma, where Prof. F. W. Padgett is giving systematic instruction in hydrocarbon chemistry and refinery technology.

ogy, the real foundation of a study of production, is insufficiently applied or understood by the average producer, and in consequence much of the production is accidental rather than scientific. When a producer finds petroleum he is simply a producer, and not a marketer, for he has usually no knowledge of the value of his product other than the posted price. He knows only in a rather vague way what characteristics are valuable; and when he has sold his crude oil he frequently is concerned no longer with the petroleum industry. The refiner usually has only the knowledge gained by an apprenticeship with an older refiner, and is therefore nescient regarding the chemistry of refining.

Petroleum marketers consider that the greatest need of those engaged in the petroleum industry today is uniformity in methods of testing and in the physical instruments employed therein. Constant progress is being made in the analytical chemistry of petroleum and its products, but much research will be necessary before precise and detailed procedures are worked out which will be satisfactory for general adoption. It is not practicable to issue standard test samples, as is the case for the iron and steel industry, but there can be laid down definite, standard instructions for carrying out the various operations involved.

A large literature already exists on the subject of analytical naphthology, owing to the activities, among others, of the American Society for Testing Materials and of the Bureau of Mines and the Bureau of Standards in the United States and of the National Physical Laboratory in England. What is needed now is the welding of these researches into a comprehensive whole by an international body of experts, which, sitting permanently like the pre-war International Petroleum Commission, shall institute researches into new methods of procedure and revise existing technic.

From the industrialist's viewpoint, the great problem in the petroleum industry is flexibility in refining, in order that there may be produced only those products which are in demand. In other words, there is wanted a suitable process which will enable the refiner to manufacture only the products for which there is a big market—say gasoline and lubricating oils. Research has been begun which has for its object the production of the desired finished oils, and only these, by purely physical methods, thus dispensing with chemical treatment.

Considerable investigation has been devoted to working

out processes for the dehydration and desulphurization of crude oils and for the pyrolysis and piezopyrolysis of heavy oils (particularly the conversion of such oils into motor fuel). Findings of importance have resulted from these investigations, but the ideal processes remain to be found, especially methods for converting products of the destructive distillation of residuum or heavy oils into saturated hydrocarbons. If hydrogenation could be conducted successfully on a commercial scale, the customary treatment with sulphuric acid might be dispensed with. Hydrogenation with platinum black or nickel could be accomplished if an antidote were known for the poisonous effect of sulphur compounds on the catalyst. Another matter of interest here is the polymerization of olefines; this subject requires the consideration of research.

Automotive engineers should have available exhaustive data regarding the specification and use of petroleum products for internal combustion and lubrication purposes. Lubricating oils for special purposes have not received due scientific attention, and, as a result, the selection of a lubricant is more frequently casual than scientific. Lubrication is a special problem of colloid physics.*

It is singular that the subject of refining has attracted so little notice. In the chemical treatment of petroleum products systematic investigation, with the object of ascertaining the most favorable temperatures for the acid treatments of petroleum distillates, would be of practical value as affording an indication to the refiner how to proceed under all circumstances. Another well-known problem in refining is the chemical treatment of lubricating oils in such manner as to minimize the losses and to prevent the emulsions which result when sulphuric acid is used. The production of persistent emulsions in the refining of petroleum is a problem to be attacked from the colloid-chemical point of view. In time much of the acid and soda treating will be eliminated from refinery practice. An economic process is needed for isolating pure naphthenic acids of high molecular weight from waste lyes. A related problem is the utilization of the esters from the naphthene carbo-acids contained in the residue from the alkali treatment. A question of interest here is: What is the cause of the cacodor of naphthenic acids, and how

*In fact, W. B. HARDY (*J. Soc. Chem. Ind.*, **38**, (1919), 7T) has shown that we may look with confidence to colloid chemistry to assist us in finding the lubricants of the future.

may these products be deodorized most effectively and economically? The utilization of naphthenic acids from Californian petroleum is under study.

The following are some of the many other problems confronting petroleum technologists: A more rational utilization of the butanes and pentanes in natural gasoline and in light petroleum fractions; does the hot still metal exert any catalytic action in the pyrolytic decomposition of residues; the minimization of the decomposition of sulphur compounds during the distillation of petroleum containing asphalt; what rôle do sulphur compounds take in the condensation of petroleum to asphalt; increasing the efficiency of tower stills, condensers, and heat exchangers; the rapid and effective revivification of spent fuller's earth; the separation of the aromatic and cyclic unsaturated hydrocarbons from the paraffin and naphthene hydrocarbons by a more satisfactory reagent than those now in use; the fractionation of petroleum residues containing paraffin wax into distillate and undecomposed amorphous wax; the elimination of gummy or asphaltic portions from wax distillate by a distillation or mechanical procedure; what constituents of a mineral oil are responsible for the lubricity thereof, and can the lubricating properties of an oil be increased in the light of this knowledge; the prevention of the oxidation of mineral oils in transformers; products which will make emulsions with water without any oil coming to the surface; and a rational plant for producing oil gas from tar and carbon monoxide from the residue, the mixed gases to be suitable for use in gas engines. Then, too, notwithstanding the many processes which have been patented, the "solidification" of petroleum and its products is still under investigation.

The collection of data on the physicochemical properties of petroleum and its products for the use of refinery chemists and engineers is one of the most important inquiries which could be instituted, and it is hoped that the Bureau of Mines will cover this field in its broadest practical aspects. The data obtained on the pure hydrocarbons which exist in crude petroleums also would be of value for purposes of comparison.

"Cracking," or pyrolysis, is regarded as the leading potentiality in petroleum refining, no less so because it permits the production of the main products according to demand, without sacrifice of byproduct possibilities. The importance of the whole matter may be evalued by having regard to the fact that at

present, even with "cracking" well launched into practice, less than one-half of the petroleum produced is manufactured into products representing an ideal apportionment of the raw material into its components. The output of gasoline may be doubled or more without increasing the production of crude petroleum.

The research activity on the subject of "cracking" has been notable, and the volume of patent applications shows no signs of diminution; in fact, the number of permutations and combinations of the variables borders on the infinite, and accordingly, while modifications of outstanding novelty will be rare, a variety of processes remain to reach the Patent Office. At the present time investigators are endeavoring to obviate the defects in nearly all the methods now in use, which are: (1) the accumulation of carbon, (2) loss of oil as fixed or permanent gas, (3) low yields, and (4) the formation of undesirable impurities.

The inclination to look upon the unsaturated products of "cracking" as valuable for synthetic chemistry is becoming pronounced. The fact that under high pressure the point of molecular scission is directed to the middle of the hydrocarbon chain, while at low pressure the point of rupture is displaced more toward the ends of the chain, holds out additional promise for the working out of commercial processes for the manufacture of isoprene, etc., from petroleum.

An insufficient amount of work is being done in a systematic way to show how to economize in the use of gasoline. A thorough investigation of carbureters and fuels, and certified tests of the performance of all makes of automobiles, would be of value in economizing in the use of gasoline, and giving the public as much service as possible for a given expenditure. The Bureau of Mines and the Bureau of Standards have studied different phases of this question, but neither has been able to conduct as much research as should be done. With over 10,000,000 of gasoline-driven automobiles in daily use, and motor gasoline constantly rising in price, the American public cannot afford to have the Government fall short in a matter of so great economic importance and of serious personal concern to so many.

A very pertinent question is, should a higher final boiling point for gasoline be permitted? A final boiling point of 230°C. would increase the available supplies by a considerable percentage, while greater efficiency in fractionation would result probably in an additional 10 per cent increase in yield.

PETROLEUM SUBSTITUTES

Even with the most efficient use of the remaining supply of petroleum and an appropriate development of oil-shale in prospect, the petroleum situation can be improved additionally by a progressive utilization of substitutes for gasoline and fuel oil, so as to give better economic balance by relieving the products upon which fall the heaviest demands. Two substances, benzol and ethyl alcohol, are suitable for assisting gasoline, and offer the advantage of a record of successful use in motor engines in Europe prior to the war, and of a marked extension of utilization there under the rigorous conditions of the present, while coal and hydro-electricity may be brought to the aid of fuel oil.

SUBSTITUTES FOR GASOLINE

The subject of gasoline substitutes is one of particular interest, although definite information concerning it is decidedly limited because of the paucity of research which has been made public. The first point of importance to mention here is that motor fuel is essentially a source of energy and that the energy must come from somewhere. Interesting stories regarding the discovery of new fuels appear from time to time in the newspapers, these fuels often being prepared by adding a small quantity of some secret compound to water. That these "fuels" are one and all without particular value is established by the fact that water contains about as little available energy as any substance which could be selected.

With respect to the real possibilities of gasoline substitutes, it now seems probable that later on shale-oil may become an important source of motor fuel. Oil shale probably will not assume any considerable industrial importance in the immediate future, but its potentiality as a resource gives a comfortable feeling of assurance that the use of motor vehicles will not have to be discontinued when crude petroleum becomes too valuable for fuel purposes. Substitutes for gasoline should receive every encouragement if produced and marketed in an intelligent and scientific manner; for our country needs to increase its motor fuel resources and no step in this direction should be hindered. It should be recognized, however, that petroleum gasoline is a type of fuel for which present equipment has been designed and for which it is eminently satisfactory. It is believed, therefore,

that when striking claims are made for the superiority of any gasoline substitute these should not be taken too seriously. The substitute fuel should be given a fair trial, but the user should be satisfied if it is as good as gasoline and should not expect it to be remarkably superior.

The type of gasoline substitute which is of most importance at the present time is the mixture of hydrocarbons, including benzol, toluol and xylol, obtained as a by-product in the coking of coal. During the war the benzols were used largely in the production of explosives and other munitions, but since the termination of hostilities a considerable supply has been rendered available for motor fuel. In fact, several companies are marketing benzol mixtures, generally mixtures of the benzols with petroleum naphtha. These products have been used under widely varying conditions, and in most cases favorable results have been obtained.

The use of light oils from coal as motor fuel does not, however, offer an ultimate solution of the motor fuel problem, since the total production of these hydrocarbons is rather limited. The quantity of light oil produced from coal in by-product coke ovens during 1919 has been estimated at 90,000,000 gal., or about 2.3 per cent of the total amount of gasoline produced in 1918.* The actual figure for hydrocarbons suitable for motor fuel is even less than that for total light oil produced, and it appears, therefore, that, as a motor fuel resource, the benzols are of relatively small importance. To illustrate, it may be stated that since 1916 the production of gasoline has practically doubled, while the quantity of coal mined has increased only about 17 per cent. The real importance of the benzols as motor fuel occurs in districts adjacent to by-product coking operations, where a reasonable proportion of the local gasoline supply may be filled by coal by-products.

In a certified dynamometer test by the Automobile Club of America 90 per cent benzol showed 12.3 per cent less fuel consumption than gasoline. At the same time the horsepower was increased, depending on the speed. At 2,000 r.p.m. this was 19.4 per cent greater than that of gasoline. The higher ignition point of benzol also eliminates "knocking" (pre-ignition). It

* Even if all our coke were manufactured in by-product ovens the amount of benzols recoverable would be only about 10 per cent of the annual consumption of gasoline.

is known that the benzols, if properly used, are very satisfactory motor fuels and that there is no difficulty in finding a market for the entire supply.

ETHYL ALCOHOL AS A MOTOR FUEL

Denatured ethyl alcohol has possibilities for the future and is being developed to a certain extent. It is interesting to note in this connection (1) that fuels with ethyl alcohol base have recently been used with success in motor vehicles in this country, in Europe, and especially in South Africa; and (2) that new sources for the production of ethyl alcohol are being discovered constantly. In addition to the generally known vegetable sources, methods have been developed for the production of ethyl alcohol from sawdust,* from refuse of cane sugar manufacture, from waste sulphite liquors, from calcium carbide, and recently, in England, at the Skinningrove Iron Co.'s works, from coke oven gas.† As the largest and best-known field of the consumption of ethyl alcohol in this country has been destroyed for the time being, its use for power purposes would not meet with the competition which it formerly would have had and the price of ethyl alcohol should not be high, especially as compared with the prices of gasoline now prevailing and expected in the near future. There are certain difficulties in the way of the wide use of ethyl alcohol as a fuel, which are of a non-technical nature and hence will not be discussed here. It may be stated, however, that the discovery of a cheap, positive and reliable denaturant would go a long way toward making possible the wide adoption of alcohol for power purposes; and that the development of cheaper methods of production and of suitable types of engines are also problems of pertinence.‡

Alcohol-benzol-naphtha mixtures are in use and have been found to be satisfactory in the present types of automobile engines. "Alcogas" is another product which has aroused interest among automotive engineers.

It would be desirable to institute broad researches (1) on the

* It is possible to get 10 to 12 l. of alcohol from 100 kg. of sawdust. There appear to be possibilities in the development of the production of alcohol from wood.

† BURY, *Iron and Coal Trades Rev.*, Dec. 19 and 26, 1919.

‡ On the comparative fuel values of gasoline and denatured alcohol in internal combustion engines, *U. S. Bureau of Mines*, see *Bull.* 43.

combustion of alcohol and alcohol mixtures, and (2) on lessening the cost of denaturing. In connection with (1) the operation of a fleet of cars and trucks fed with such mixtures would provide data of importance.

FUEL OIL SUBSTITUTES

Fuel oil has come into extensive use in the United States, especially in the far West, as a substitute for coal.* It is more convenient than coal and therefore is adopted by industries wherever its price is low enough to permit its use. Its employment in this way cannot be sustained, in view of the slowing rate of petroleum production and the counter-demand that will come in increasing measure from the further development of pyrolytic practice in refining and from the wider adoption of the Diesel type of internal-combustion engine. It soon will be necessary, therefore, in any event, to bring coal and hydro-electric power to the aid of a growing number of those activities now dependent upon oil fuel; and the whole matter may be facilitated, to the benefit of the petroleum resource in particular, by constructive action in respect to coal and water power, so as to make their service in this respect more immediately available.

The use of the tar obtained in by-product coking (9 to 10 gal. per ton) for fuel, especially in steel manufacture, has increased rapidly during the past few years, and many of the larger steel companies, operating their own by-product coke plants, do not sell any of their tar for distillation purposes, but use it exclusively for fuel. In open hearth practice the consumption of tar per ton of steel is reported to be 10 per cent. less than the consumption of fuel oil. It is used advantageously in combination with producer gas. The resulting flame has a much better melting efficiency than that of straight producer gas, and the increase in the capacity of the furnace is much greater than would be accounted for on the basis of the heating value of the fuel used. These considerations are of great moment, in view of the increasing price of fuel oil and at a time when the maximum output per unit of investment is essential. The price of approximately 4 cts. per gal., that has until recently been paid by tar-distilling companies for crude tar, is much too low to meet competition

* The substitution of petroleum for coal has gained considerable headway in the large textile and paper mills, and even in small industries in the New England section.

with the real fuel value, and the future is bound to see a scarcity of tar for distillation, which will result in a considerable increase in price.

INCREASING THE USEFULNESS OF FUEL OILS

It is of interest to note what has been done recently to supplement mineral oils or to increase their usefulness through research. The work has been carried on in several directions, of which the following may be mentioned, without, however, indicating the relative importance of the various remedies.

Processes have been devised for making stable mixtures of tars with mineral oil by using pitch-containing tars, asphaltic residuum and a suitable distillate. It also has been found that fuel oils or residues may be reduced in viscosity by piezochemical means.

During the war the Submarine Defense Association developed the so-called *colloidal fuel*, a mixture of oil and pulverized coal wherein the coal is held in suspension in the oil through the presence of a peptizing agent, called by its inventors the "fixateur." The addition of 1 per cent of "fixateur" to a mixture of 60 to 70 per cent of oil and 40 to 30 per cent of coal dust forms a sort of colloid suspension which remains homogeneous for long periods. It is claimed that this product may be used for oil-fired furnaces in about the same manner as fuel oil, and that it provides (when high-grade coal is used) a fuel of even higher calorific value per unit volume than the original oil.

Next, in particular reference to motor cars, may be mentioned the possible use of *engines of the Diesel type*. Numerous attempts have been made in this direction without noteworthy success, which has been explained by the statement that the Diesel-engine manufacturers are too busy to undertake work on the problem, while motor car manufacturers do not know enough about Diesel engines. The use of modified Diesel engines on motor cars would relieve the situation to the extent of permitting the use of unrefined oils, instead of only such products as gasoline and kerosene.

THE USE OF OIL IN GAS MANUFACTURING

It cannot be gainsaid that the use of gas oil, a high-grade fuel oil, in the manufacture of "city gas" is a practice which is

unjustifiable on the basis of resource economy. Approximately 6 per cent of our petroleum production is employed for this purpose, and the product is used for cooking and lighting by millions of people and by the industries in a number of ways. A large part of this gas is made by the use of oil to enrich blue water gas of low heating value. Recently this gas oil has become scarcer, and it is likely to become still more expensive and perhaps impossible to obtain in sufficient quantity. This condition will necessitate the use of lower grades of oil, or the production of lower grades of gas, or a change of manufacturing equipment at enormous expense. Individual gas companies cannot investigate so fundamental a question comprehensively; and individual cities or states cannot assume the responsibility of solving the problem for the entire country. The proper agency to take up this question is the Federal Government, with the cooperation of the gas companies and the oil companies and the state and municipal authorities. Such a broad and constructive study would be of high importance and would receive the concurrence of all important interests. It should include research on raw materials, manufacturing methods, and the relative usefulness of the various grades of gas that can be produced.

RESEARCH ON CHEMICAL PRODUCTS FROM CRUDE PETROLEUM

Some petroleum economists take the view that later on, when there is evidence that crude petroleum will be unable to compete with its substitutes, it will be possible to obtain so many more valuable products from its distillates that the use of any one of these as a fuel will be condemned from the standpoint of conservation. Petroleum then will constitute the basis of a chemical products industry which will be as distinct in scope and activity as the coal tar industry of the present time. In fact, several of the prominent refining companies have in progress investigatory work which will enable them to accumulate a reserve of technical knowledge respecting the manufacture of various chemical products from crude petroleum.

Some attention has been given to the production of drying or siccative oils from petroleum. It is claimed by the De Bataafsche Petroleum Maatschappij that an oil, the drying properties of which are comparable with those of linseed oil, may be obtained by chlorinating a mineral oil fraction of the specific gravity 0.885 at 15°C., in such a manner that 1,000 liters

of it absorb 800 kg. of chlorine, and then heating the chlorinated product with the addition of zinc dust to 290 to 300°C., until the chlorine has been expelled quantitatively as hydrochloric acid. The problem is to produce an oil economically which will be devoid of tackiness. Artificial resins also may be obtained by the chlorination of petroleum and its distillates; but the reduction of the time of the reaction and the purity of the products present important difficulties. The systematic study of the action of reagents on petroleums—a field which merely has been entered—will provide material for the solution of problems of this character. A subject which already has received some investigation is the conversion of chloroparaffins into esters.

A problem of constant interest is the synthetic preparation of fatty acids from petroleum and certain of its products; for when an economic process is available for the manufacture of these acids a working basis will be had for the production of edible products, some of the acids obtainable being convertible into glycerides. Considerable attention has been and is being given to the study of this problem.

The Russian naphthochemist Zelinskii has been one of the pioneers in the application of the Grignard reaction for the production of fatty acids from petroleum, and so long ago as 1902 he took out a German patent (No. 151880) for the chlorination of certain petroleum fractions. The fraction 132–145°C. of a Russian petroleum was chlorinated, treated in ethyl ether solution with magnesium and carbon dioxide, and the resulting magnesium salt decomposed with dilute sulphuric acid. An acid, $C_{10}H_{18}O_2$, was obtained which, on heating with glycerin at 250°C., yielded a di-glyceride and a tri-glyceride to the extent of 60 per cent of the theoretical, according to Zelinskii.* In normal times, however —that is to say, at pre-war prices—this could not have competed with natural fats;† but, according to reports, it was otherwise under war conditions, and it has been said that the Vereinigte Chemische Werke a. G., of Charlottenburg, Germany, was able to manufacture fat on a commercial scale by the Zelinskii process.

Chemists who have attempted to repeat Zelinskii's work have found that the yields are very small.‡ The reasons for this are several, the principal among which are the following:

* See *Z. angew. Chem.*, **16** (1903), 37.

† Colletas, *Mat. Grasses*, **7** (1914), 4151.

‡ Brooks, *Met. Chem. Eng.*, **18** (1918), 388.

1. The formation of the magnesium complex is very slow with derivatives containing more than eight or ten carbon atoms.

2. It is well known that the higher magnesium alkyl halides react with a second molecule of the original alkyl halide to give a hydrocarbon and magnesium halide; for example:

$$C_7H_{15}MgBr+C_7H_{15}Br \rightarrow C_{14}H_{30}+MgBr_2.$$

3. Brooks has found that the halogen derivatives of petroleum hydrocarbons of 10 to 20 or more carbon atoms are unstable and slowly break down on standing at room temperature, to give free halogen acids and hydrocarbons which appear to be mainly saturated ring compounds.

4. Stadnikov* has demonstrated that the alkyl magnesium halide and ether complex breaks down in a variety of ways. For example, Stadnikoy showed that a complex made from magnesium propyl iodide, carbon dioxide and benzhydrylbutyl ether yielded a mixture of several hydrocarbons, free carbon dioxide and mixed ethers, only a trace of acid being obtained.

Schultz in 1912–13 studied the oxidation of mineral oil fractions; but the percentage of fatty acid obtained was stated to be very small, the main oxidation products being aldehydes. Some of the best results are said to have been obtained by the oxidation of paraffin.† The Chemische Fabrik Troisdorf (Drs. Hülsberg and Seiler) has patented the following method: Air or oxygen is led into a vessel containing melted paraffin, for about fifty hours, at a temperature of 100 to 120°C., mercuric oxide or previously oxidized paraffin being utilized as a catalyst. It is said that the products consist partly of oleic acid and partly of volatile substances, but nothing definite has been divulged respecting the yields of oleic or other fatty acids. A somewhat similar method is that of the A. G. für Mineralölindustrie vorm. (David Fanto & Co.), of Pardubitz, Bohemia. It has been stated that this firm has been working on a large scale, since 1915, a process which consists mainly in blowing air into paraffin for 15 to 18 days at a temperature of 130 to 135°C. (See also English Patents Nos. 131301, 131302, 131303, and 133027.) The yield is calculated at about 60 per cent. According to reports, a fatty acid, $C_{11}H_{22}O_2$, of melting point 53.7°C., thus has been obtained,

* See *Ber.*, **44**, 1157; **47**, 2, 133; *J. Russ. Phys. Chem. Soc.*, **47**, 1122, 2037, and 2115.

† Cf., however, Wegrzyn, *Petroleum*, **13**, 24, who made entirely unsuccessful attempts to obtain fatty acids from solid paraffin.

together with an iso-palmitic acid, $C_{16}H_{32}O_2$, of melting point 38.4°C., and lignoceric acid, $C_{24}H_{48}O_2$, of melting point 80°C.

The methods so far known are considered to be of practically no value for preparing fatty acids from petroleum, even for the purpose of laboratory research. In illustration, it may be mentioned that hydrogen and fatty acids result from the fusion of the higher alcohols with potassium hydroxide, but only the higher primary alcohols give good yields. The secondary alcohols are slightly oxidized under these conditions and yield mostly condensation products, while the higher tertiary alcohols break down, giving acids having a less number of carbon atoms. Moreover, it has been shown that the alcoholates of the higher alcohols react with carbon monoxide under high pressures, but the principal products formed are esters of formic acid and not the higher fatty acids. The known methods for preparing alcohols direct from petroleum olefines yield only secondary and tertiary alcohols. And then no methods for adding halogens or halogen acids to the saturated or unsaturated hydrocarbons are known which give satisfactory yields of primary derivatives.

A variety of methods also have been proposed for oxidizing saturated and unsaturated hydrocarbons by air in the presence of various other substances and many wet methods have been tried; but in general the results are carbon dioxide, water, resinous or asphaltic material, and traces of the simple fatty acids, such as acetic, propionic, butyric, etc., which usually have not been obtained in quantities sufficient for positive identification. Our knowledge of hydrocarbon chemistry is unsatisfactory, and hence in real need of the revision of research. The commercial production of fatty acids from petroleum may some day be accomplished, but not by the methods of synthesis now known and not until there has been obtained a much more extensive and quantitative knowledge of the nature and behavior of hydrocarbons such as constitute petroleum oils.

The lowest boiling fraction of petroleum, of the composition C_5H_{12}, may be used for the preparation of isoprene: by systematic chlorination, isomerization, and liberation and addition of hydrochloric acid, the three hydrocarbons present (iso- and normal petane and tetramethylmethane) all can be converted into isoprene. But much more investigation will be required before isoprene can be manufactured profitably from hydrocarbon complexes.

It is thought that a simple, direct process for obtaining the butadiene hydrocarbons from petroleum soon will be found, and thus a good route to synthetic rubber will be opened up. Pyhälä has shown that the fraction of Baku petroleum boiling between 98 and 106°C. yields up to about 20 per cent. of its weight of adipic acid, which, by way of the amide, can be converted into butadiene.* This method of preparation is, however, hardly possible from a commercial standpoint, and butadiene usually is obtained technically from benzene or phenol.

It is of interest to mention in this place that the emulsions obtained with the turpentine-like and other hydrocarbons of petroleum by the aid of certain emulsifying agents are similar to rubber latex and can be worked up into rubber-like products.

Finally, it may be noted that the production of dyestuffs from petroleum is an open field for research exploration. Kharitchkov† has found that the nitro-derivatives obtained by treating machine or spindle oils with warm nitric acid (specific gravity, 1.50) are related to the nitro-compounds obtained by nitrating polynaphthenic acids and used in the preparation of dyestuffs. Nitro-products which yield with alkalies brown substantive dyestuffs and with sulphur and alkalies brown to brown-velvet sulphur dyestuffs have been obtained by the nitration of the higher fractions from Galician petroleum.‡ The preparation of aromatic hydrocarbons from fatty hydrocarbons—especially the preparation of benzene and its homologues from petroleum—requires investigation along broad lines, although the subject is not of technical interest here at present. Crude petroleums from some Bornean and Persian fields are aromatic-rich and provided toluene for TNT manufacture during the European war.

While one-fifth of the domestic consumption of petroleum is utilized as fuel, most of the crude oil is refined into products which possess wider usefulness and higher value to society than the raw material, and refining practice is in continuous flux to adapt petroleum to a varying and widening demand. Under present technical procedure, however, petroleum yields only several hundred substances of commercial importance, but no limit can be set to the number of useful products that scientific inquiry may wrest from this raw material. Indeed, the

* *Petroleum*, **9** (1914), 1376.

† *Chem. Ztg.*, **37** (1913), 869.

‡ See FREUND, *Z. angew. Chem.*, **25**, 1058.

field of petroleum by-products represents one of the most attractive research opportunities that exist in this country today. It has been observed by Gilbert and Pogue* that—

> In this connection an interesting vision opens up as to how a great oil by-products industry, through the values accruing to successive refinements of products, may be led to contribute more than it now does to the expense of petroleum production, relieving to that extent the cost distributed among the products universally used in bulk, such as gasoline. It would seem that a far-sighted economic policy, properly directed, might eventually contribute to a lowering cost for motor fuel, just as a proper shaping of coal economics could be made to relieve the focus of expense now exclusively borne by fuel coal—the two conspiring to lower the cost of living.

The time may be foreseen when, through the accomplishments of technochemical investigation, the petroleum industry will yield a range of fuels for the internal-combustion engine only; kerosene in quantity narrowing to that desirable for country use and export trade; lubricating oils adjusted to the growing demands of mechanical power; and an ever-widening range of chemical products supporting a great petroleum by-products industry, rivalling if not exceeding the coal-products industry in importance. In respect to the last, it should be emphasized that the United States today faces an opportunity similar to that which 20 years ago confronted both Germany and the United States as regards the manufacture of dyestuffs, explosives, fertilizers, drugs and other chemicals from the non-fuel components of coal.

PETROLEUM AND THE EUROPEAN WAR

It has been said that the success of the Allies in the European war was due largely to the supply and utilization of petroleum. Certainly, as Dunstan has remarked,† without mineral oil warfare would have remained in a mediæval condition and an impasse might have resulted. As we now know warfare, it is impossible to conceive of strategy and tactics deprived of oil-fired ships, motor transport, aircraft, tractors, tanks, and flame projectors, while industry at home lacked internal-combustion engine fuel and lubricants. The vital importance of the reaction of petroleum on the great struggle was pointed out clearly and forcibly at

* U. S. Nat. Museum, *Bull.* **102**, I, 2.

† "Reports of the Progress of Applied Chemistry," **4** (1919), 66.

the annual dinner of the Institution of Petroleum Technologists in 1919.*

The principal problems confronting the Allies were:

1. Whether the world could produce the aggregate supplies that were required for the service of the war.

2. Whether the processes of refining could be so adjusted that increased quantities of heavy fuel could be obtained as well as of gasoline, particularly of the high grade required for aviation purposes.

3. Whether sufficient tankers, cars and receptacles could be provided to transport and distribute by sea and land the necessary quantities of each product.

All these problems were solved satisfactorily—a fact which reflects the greatest credit to the large petroleum companies as well as to those who acted for the governments.

An enormous amount of intensive research was initiated throughout the war, and it is not too much to state that a wider and deeper knowledge of naphthology is one of the good results of the conflict. Immediately after this country entered the war the splendid facilities of the laboratories of the important refining companies and of the Bureau of Mines were offered to the War Department for experimental work, and the acceptance resulted in considerable investigational activity. Perhaps the most valuable contributions were made on fuels for airplane motors, products of "cracking" processes, lubricating oils, and the inspection of fuel oils. The standardization of motor gasoline and lubricating oils, and specifications therefor for Government purchase, emanated from the committee on the standardization of petroleum specifications of the Fuel Administration.

* *J. Inst. Pet. Tech.*, **5** (1919), 221 *et seq.*

APPENDIX I

METHODS FOR THE ANALYSIS OF COAL

FINAL REPORT OF THE JOINT COMMITTEE OF THE AMERICAN SOCIETY FOR TESTING MATERIALS AND THE AMERICAN CHEMICAL SOCIETY*

The *Joint Committee on Coal Analysis*, which had been at work on the subject since the fall of 1911, consisted of the following members: W. A. Noyes, *Chairman;* Perry Barker, H. C. Dickinson, A. C. Fieldner, Frank Haas, W. F. Hillebrand, S. W. Parr, S. S. Voorhees, A. H. White.

The work of the joint committee was carried on chiefly through the agency of the following sub-committees:

1. Preparation of laboratory samples, including loss of moisture in sampling: Fieldner, *Chairman;* Hass, Hillebrand, Voorhees, Parr and Barker.
2. Moisture: Hillebrand, *Chairman;* Fieldner, Parr.
3. Deterioration: Parr, *Chairman;* Fieldner, Haas, Dickinson.
4. Volatile matter: Parr, *Chairman;* Fieldner, Haas, Dickinson.
5. Fixed carbon and ash: Parr, *Chairman;* Fieldner, Hillebrand.
6. Sulphur: Barker, *Chairman;* Voorhees, Dickinson.
7. Phosphorus: Hillebrand.
8. Ultimate analysis: Fieldner, *Chairman;* Parr, White.
9. Calorimetric determination: Dickinson, *Chairman;* Haas, Barker.

Three preliminary reports were published, one in *J. Ind. Eng. Chem.*, **5** (1913), 517; a second as the Report for 1914 of Committee E-4 in *Proc.* **14**, Am. Soc. Test. Mat.; the third as the tentative final report in 1915. The present report is the same as the report submitted in 1915 with the exception of a few verbal changes. The report has been accepted by letter ballot as the official, final report of the American Society for Testing Materials and is recommended for the use of chemists and as a basis for specifications to be used in the purchase of coal. (Many details given in the preliminary reports are not repeated here.)

The report has been approved unanimously by the members of the committee and has been approved by the Supervisory Committee on Standard Methods of Analysis of the American Chemical Society.

* Reprinted from the *J. Ind. Eng. Chem.*, **9** (1917), 100.

PREPARATION OF LABORATORY SAMPLES

Apparatus

Air-drying Oven.—The oven is to be used for air-drying wet samples and may be of the form shown in Fig. 377. This is not absolutely necessary but is economical where many wet samples are received.*

Galvanized-iron pans 18 *by* 18 *by* 1½ *in. deep* for air-drying wet samples.

Balance or solution scale for weighing the galvanized-iron pans with samples. It should have a capacity of 5 kg. and be sensitive to 0.5 grams.

Jaw crusher for crushing coarse samples to pass a 4-mesh sieve.

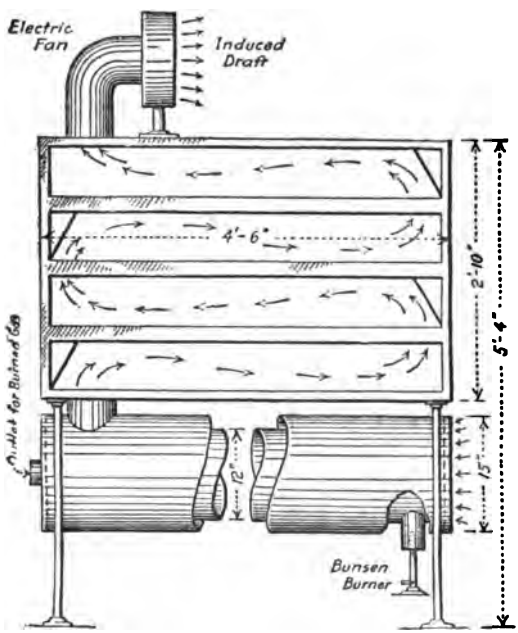


Fig. 377.—Drier for coarse samples. The outlet for air at the top may be connected with a chimney or any other device which will furnish a suitable draft. (*Bull.* 9, *Geol. Surv., Ohio*, 312.)

Roll crusher or coffee-mill type of grinder for reducing the 4-mesh product to 20-mesh. The coffee-mill type of grinder should be entirely enclosed and have an enclosed hopper and a receptacle capable of holding 10 lb. of coal. This is to reduce the moisture losses while crushing.

Abbé ball mill, planetary disc crusher, chrome-steel bucking board, or any satisfactory form of pulverizer for reducing the 20-mesh product to 60-mesh.

* For details of air-drying oven see Bownocker, Lord and Somermeier, "Coal," *Bull.* **9**, 4th Series, Ohio Geological Survey, p. 312 (1908); or F. M. Stanton and A. C. Fieldner, "Methods of Analyzing Coal and Coke," U. S. Bureau of Mines, *Tech. Paper*, **8**, p. 4 (1912); or E. E. Somermeier, "Coal, Its Composition, Analysis, Utilization and Valuation," p. 71, McGraw-Hill Book Co., Inc. (1912).

The porcelain jars for the ball mill should be approximately 9 in. in diameter and 10 in. high. The flint pebbles should be smooth, hard and well rounded.

A large riffle sampler, with ½- or ⅝-in. divisions for reducing the 4-mesh sample to 10 lb. (Fig. 378).*

A small riffle sampler, with ¼- or ⅜-in. divisions for dividing down the 20- and 60-mesh material to a laboratory sample (Fig. 378).

An 8-in. 60-mesh sieve with cover and receiver.

Containers for Shipment to Laboratory.—Samples in which the moisture content is important should always be shipped in moisture-tight containers. A galvanized-iron or tin can with a screw top which is sealed with a rubber

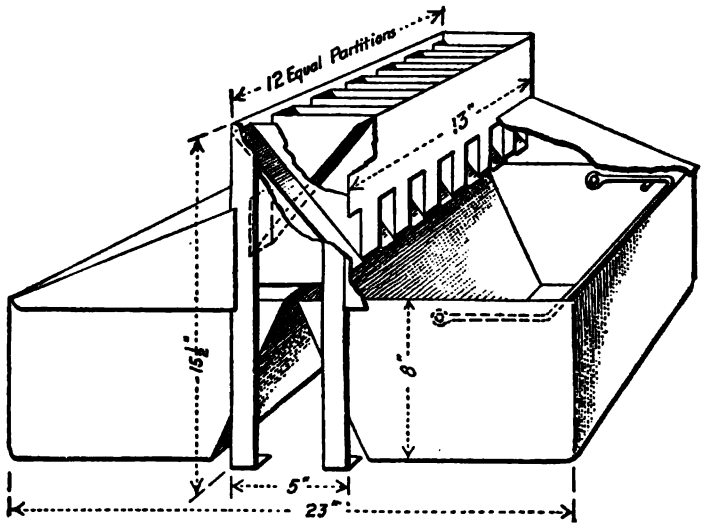


FIG. 378.—Riffle sampler. (*Bull. No. 9, Geol. Surv., Ohio*, 313.)

gasket and adhesive tape is best adapted to this purpose. Glass fruit jars sealed with rubber gaskets may be used, but require very careful packing to avoid breakage in transit. Samples in which the moisture content is of no importance need no special protection from loss of moisture.

METHOD OF SAMPLING

A. When Coal Appears Dry.—If the sample is coarser than 4-mesh (0.20 in.) and larger in amount than 10 lb., quickly crush it with the jaw crusher to pass a 4-mesh sieve and reduce it on the larger riffle sampler to 10 lb.;† then crush at once to 20-mesh by passing through rolls or an enclosed grinder, and take, without sieving, a 60-gram total moisture sample, immediately after the material has passed through the crushing apparatus. This sample should be taken with a spoon from various parts of the 20-mesh product, and should be placed directly in a rubber-stoppered bottle.

*E. E. SOMERMEIER, "Coal, Its Composition, Etc.," McGraw-Hill Book Co., Inc. (1912).

†If the sample is crushed to pass a 6-mesh screen it may be reduced to 5 lb.

Thoroughly mix the main portion of the sample, reduce on the small riffle sampler to about 120 grams, and pulverize to 60-mesh by any suitable apparatus without regard to loss of moisture. After all the material has been passed through the 60-mesh sieve, mix and divide it on the small riffle sampler to 60 grams. Transfer the final sample to a 4-oz. rubber-stoppered bottle. Determine moisture in both the 60- and the 20-mesh samples by the method given under moisture.

Computation.—Compute the analysis of the 60-mesh coal, which has become partly air-dried during sampling, to the dry-coal basis, by dividing each result by 1 minus its content of moisture. Compute the analysis of the coal "as received" from the dry-coal analysis by multiplying by 1 minus the total moisture found in the 20-mesh sample.

B. When Coal Appears Wet.—Spread the sample on tared pans, weigh, and air-dry at room temperature, or in the special drying oven, shown in Fig. 377, at 10 to 15°C., above room temperature and weigh again. The drying should be continued until the loss in weight is not more than 0.1 per cent. per hour. Complete the sampling as under dry coal.

Computation.—Correct the moisture found in the 20-mesh, air-dried sample to total moisture "as received," as follows:

$$\frac{(100 - \text{per cent. air-drying loss}) \times (\text{per cent. moisture in 20-mesh coal})}{100} + \text{per cent. air-drying loss} = \text{total moisture "as received"}$$

Compute the analysis to "dry-coal" and "as-received" bases as under dry coal, using for the "as-received" computation the total moisture as found by the formula in place of the moisture found in the 20-mesh coal.

NOTES.—Freshly mined or wet coal loses moisture rapidly on exposure to the air of the laboratory, hence the sampling operations between opening the container and taking the 20-mesh total-moisture sample must be conducted with the utmost dispatch and with minimum exposure to air.

The accuracy of the method of preparing laboratory samples should be checked frequently by resampling the rejected portions and preparing a duplicate sample. The ash in the two samples should not differ more than the following percentages.

	PER CENT
No carbonates present	0.4
Considerable carbonate and pyrite present	0.7
Coals with more than 12 per cent. ash, containing considerable carbonate and pyrite	1.0

DETERMINATION OF MOISTURE

APPARATUS

Moisture Oven.—This must be so constructed as to have a uniform temperature in all parts and a minimum of air space. It may be of the form shown in Fig. 379. Provision must be made for renewing the air in the oven at the rate of two to four times a minute, with the air dried by passing it through concentrated sulphuric acid.

Capsules with Covers.—A convenient form, which allows the ash determination to be made on the same sample, is the Royal Meissen porcelain capsule No. 2, ⅞ in. deep and 1¾ in. diameter; or a fused silica capsule of

similar shape. This is to be used with a well-fitting flat aluminum cover, illustrated in Fig. 380.

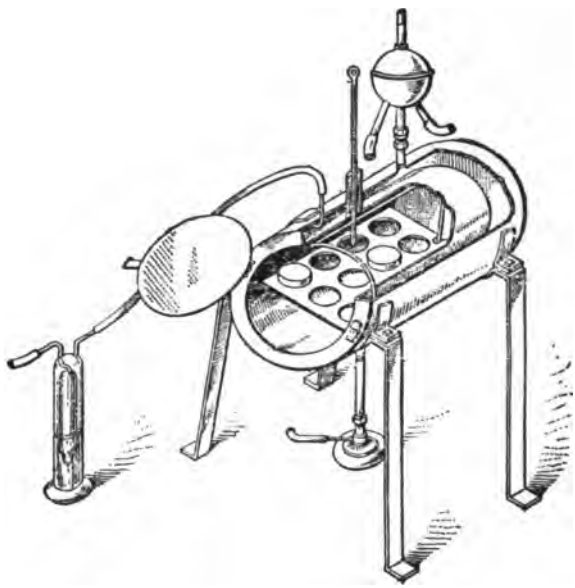


FIG. 379.—Toluene or glycerine and water oven for determining moisture. (*Tech. Paper* 76, *Bureau of Mines*, 16.)

Glass capsules with ground-glass caps may also be used. They should be as shallow as possible, consistent with convenient handling.

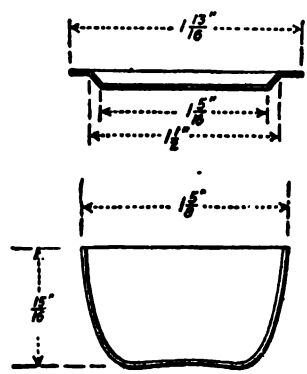


FIG. 380.—Porcelain capsule with flat aluminum cover.

METHOD

(*A*) *Sixty-mesh Sample.*—Heat the empty capsules under the conditions at which the coal is to be dried, stopper or cover, cool over concentrated sulfuric acid (sp. gr. 1.84) for 30 min., and weigh. Dip out with a spoon or

spatula from the sample bottle approximately 1 gram of coal; put this quickly into the capsule, close, and weigh at once.

An alternative procedure (more open to error), after transferring an amount slightly in excess of 1 gram, is to bring to exactly 1 gram in weight (±0.5 mg.) by quickly removing the excess weight of coal with a spatula. The utmost dispatch must be used in order to minimize the exposure of the coal until the weight is found.

After removing the covers, quickly place the capsules in a pre-heated oven (at 104 to 110°C.) through which passes a current of air dried by concentrated sulfuric acid. Close the oven at once and heat for 1 hr. Then open the oven, cover the capsules quickly and place them in a desiccator over concentrated sulfuric acid. When cool, weigh.

(*B*) *Twenty-mesh Sample.*—Use 5-gram samples weighed with an accuracy of 2 mg. and heat for 1½ hr.; the procedure is otherwise the same as with the 60-mesh sample. Methods of greater accuracy for the determination of moisture are given in the preliminary report.

The permissible differences in duplicate determinations are as follows:

	Same analyst	Different analysts
Moisture under 5 per cent.....	0.2 per cent	0.3 per cent
Moisture over 5 per cent.....	0.3 per cent	0.5 per cent

DETERMINATION OF ASH

Apparatus

Gas or Electric Muffle Furnace.—The muffle should have good air circulation and be capable of having its temperature regulated between 700 and 750°C.

Porcelain Capsules.—Royal Meissen porcelain capsules No. 2, ⅞ in. deep and 1¾ in. in diameter, or similar shallow dishes.

Method

Place the porcelain capsules containing the dried coal from the moisture determination in a cold muffle furnace or on the hearth at a low temperature and gradually heat to redness at such a rate as to avoid mechanical loss from too rapid expulsion of volatile matter. Finish the ignition to constant weight (±0.001 gram) at a temperature between 700 and 750°C. Cool in a desiccator and weigh as soon as cold.

The permissible differences in duplicate determinations are as follows:

	Same analyst	Different analysts
No carbonates present.....	0.2 per cent	0.3 per cent
Carbonates present.....	0.3 per cent	0.5 per cent
Coal with more than 12 per cent. of ash, containing carbonates and pyrite.....	0.5 per cent	1.0 per cent

Notes.—Before replacing the capsules in the muffle for ignition to constant weight, the ash should be stirred with a platinum or nichrome wire. Stirring once or twice before the first weighing hastens complete ignition.

The result obtained by this method is "uncorrected" ash. For "corrected" ash see the preliminary report. The actual mineral matters in the original coal are usually very different in weight and composition from the weight of the "uncorrected" ash.

DETERMINATION OF VOLATILE MATTER

Apparatus

Platinum Crucible with Tightly Fitting Cover.—The crucible should be of not less than 10 nor more than 20 c.c. capacity; of not less than 25 nor more than 35 mm. diameter; of not less than 30 nor more than 35 mm. height.

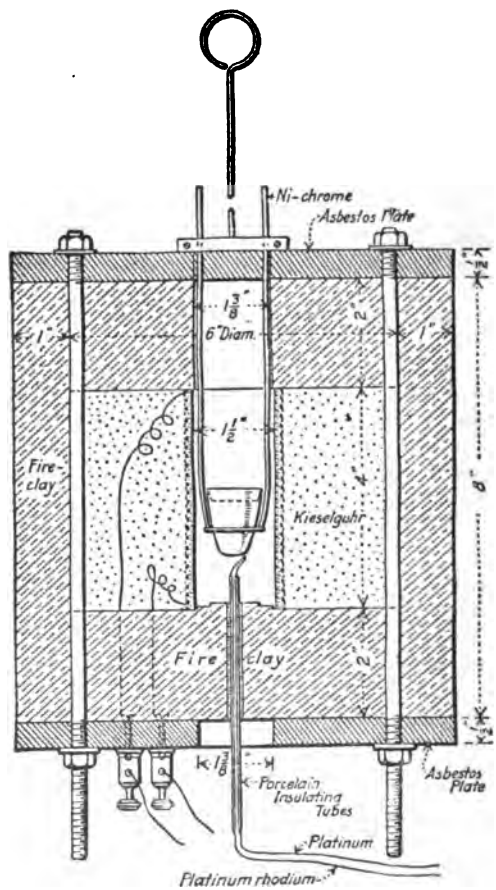


FIG. 381.—Electric tube furnace for determining volatile matter. (*Tech. Paper* 76, *Bureau of Mines.*)

Vertical Electric Tube Furnace; or a Gas or Electrically Heated Muffle Furnace.—The furnace may be of the form shown in Fig. 381. It is to be regulated to maintain a temperature of 950°C. (±20°C.) in the crucible as

shown by a thermocouple kept in the furnace. If the determination of volatile matter is not an essential feature of the specifications under which the coal is bought a Méker burner may be used.

METHOD

Weigh 1 gram of the coal in a weighed 10 to 20 c.c. platinum crucible, close with a capsule cover and place on platinum or nichrome-wire supports in the furnace chamber, which must be kept at a temperature of 950°C. (±20°C.). After the more rapid discharge of volatile matter has subsided, as shown by the disappearance of the luminous flame, tap the cover lightly to seal the crucible more perfectly and thus guard against the admission of air. After heating exactly 7 min. remove the crucible from the furnace and without disturbing the cover allow it to cool. Weigh as soon as cold. The loss of weight minus moisture equals the volatile matter.

Modification for Sub-bituminous Coal, Lignite and Peat.—Mechanical losses are incurred on suddenly heating peat, sub-bituminous coal, and lignite; therefore they must be subjected to a preliminary gradual heating for 5 min.; this is best done by playing the flame of a burner upon the bottom of the crucible, in such manner as to bring about the discharge of volatile matter, at a rate not sufficient to cause sparking. After the preliminary heating, transfer the crucible to the volatile-matter furnace and heat for 6 min. at 950°C. as in the regular method.

The permissible differences in duplicate determinations are as follows:

	SAME ANALYST	DIFFERENT ANALYSTS
Bituminous coals	0.5 per cent	1.0 per cent
Lignites	1.0 per cent	2.0 per cent

NOTES.—The cover should fit closely enough so that the carbon deposit from bituminous and lignite coals does not burn away from the under side.

Regulation of temperature to within the prescribed limits is important.

DETERMINATION OF FIXED CARBON

Compute fixed carbon as follows:

100 − (per cent moisture + per cent ash + per cent volatile matter) = Fixed carbon

DETERMINATION OF SULFUR BY THE ESCHKA METHOD

APPARATUS

Gas or electric muffle furnace, or burners for igniting coal with the Eschka mixture and for igniting the barium sulfate.

Porcelain, silica, or platinum crucibles or capsules for igniting coal with the Eschka mixture.

No. 1 Royal Meissen Porcelain Capsule, 1 In. Deep and 2 In. in Diameter.—This capsule, because of its shallow form, presents more surface for oxidation and is more convenient to handle than the ordinary form of crucible.

No. 1 Royal Berlin porcelain crucibles, shallow form, and platinum crucible of similar size may be used. Somewhat more time is required to burn

out the coal, owing to the deeper form, than with the shallow capsules described above.

No. 0 or 00 porcelain crucibles, or platinum, alundum or silica crucibles of similar size are to be used for igniting the barium sulfate.

Solutions and Reagents

Barium Chloride.—Dissolve 100 grams of barium chloride in 1,000 c.c. of distilled water.

Saturated Bromine Water.—Add an excess of bromine to 1,000 c.c. of distilled water.

Eschka Mixture.—Thoroughly mix 2 parts (by weight) of light calcined magnesium oxide and 1 part of anhydrous sodium carbonate. Both materials should be as free as possible from sulphur.

Methyl Orange.—Dissolve 0.02 gram in 100 c.c. of hot distilled water and filter.

Hydrochloric Acid.—Mix 500 c.c. of hydrochloric acid (sp. gr. 1.20) and 500 c.c. of distilled water.

Normal Hydrochloric Acid.—Dilute 80 c.c. of hydrochloric acid (sp. gr. 1.20) to 1 liter with distilled water.

Sodium Carbonate.—A saturated solution: approximately 60 grams of crystallized or 22 grams of anhydrous sodium carbonate in 100 c.c. of distilled water.

Sodium-hydroxide Solution.—Dissolve 100 grams of sodium hydroxide in 1 liter of distilled water. This solution may be used in place of the sodium-carbonate solution.

Method

Preparation of Sample and Mixture.—Thoroughly mix on glazed paper 1 gram of coal and 3 grams of Eschka mixture. Transfer to a No. 1 Royal Meissen porcelain capsule, 1 in. deep and 2 in. in diameter, or a No. 1 Royal Berlin crucible or a platinum crucible of similar size, and cover with about 1 gram of Eschka mixture.

Ignition.—On account of the amount of sulphur contained in artificial gas, the crucible shall be heated over an alcohol, gasoline or natural gas flame as in procedure (*a*) below or in a gas or electrically heated muffle as in procedure (*b*) below. The use of artificial gas for heating the coal and Eschka mixture is permissible only when the crucible is heated in a muffle.

(*a*) Heat the crucible, placed in a slanting position on a triangle, over a very low flame to avoid rapid expulsion of the volatile matter, which tends to prevent complete absorption of the products of combustion of the sulphur. Heat the crucible slowly for 30 min., gradually increasing the temperature and stirring after all black particles have disappeared, which is an indication of the completeness of the procedure.

(*b*) Place the crucible in a cold muffle and gradually raise the temperature to 870 to 925°C. (cherry-red heat) in about 1 hour. Maintain the maximum temperature for about 1½ hr. and then allow the crucible to cool in the muffle.

Subsequent Treatment.—Remove and empty the contents into a 200 c.c. beaker and digest with 100 c.c. of hot water for ½ to ¾ hr., with occasional stirring. Filter and wash the insoluble matter by decantation. After several washings in this manner, transfer the insoluble matter to the filter

and wash 5 times, keeping the mixture well agitated. Treat the filtrate, amounting to about 250 c.c. with 10 to 20 c.c. of saturated bromine water, make slightly acid with hydrochloric acid and boil to expel the liberated bromine. Make just neutral to methyl orange with sodium hydroxide or sodium carbonate solution, then add 1 c.c. of normal HCl. Boil again and add slowly from a pipette, with constant stirring, 10 c.c. of a 10 per cent solution of barium chloride ($BaCl_2.2H_2O$). Continue boiling for 15 minutes and allow to stand for at least 2 hr., or preferably over night, at a temperature just below boiling. Filter through an ashless filter paper and wash with hot distilled water until a silver nitrate solution shows no precipitate with a drop of the filtrate. Place the wet filter containing the precipitate of barium sulphate in a weighed platinum, porcelain, silica or alundum crucible, allowing a free access of air by folding the paper over the precipitate loosely to prevent spattering. Smoke the paper off gradually and at no time allow it to burn with flame. After the paper is practically consumed, raise the temperature to approximately 925°C. and heat to constant weight.

The residue of magnesia, etc., after leaching, should be dissolved in hydrochloric acid and tested with great care for sulphur. When an appreciable amount is found this should be determined quantitatively. The amount of sulphur retained is by no means a negligible quantity.*

Blanks and Corrections.—In all cases a correction must be applied either (1) by running a blank exactly as described above, using the same amount of all reagents that were employed in the regular determination, or more surely (2) by determining a known amount of sulphate added to a solution of the reagents after these have been put through the prescribed series of operations. If this latter procedure is adopted and carried out, say, once a week or whenever a new supply of a reagent must be used, and for a series of solutions covering the range of sulphur content likely to be met with in coals, it is only necessary to add to or subtract from the weight of barium sulphate obtained from a coal, whatever deficiency or excess may have been found in the appropriate "check" in order to obtain a result that is more certain to be correct than if a "blank" correction as determined by the former procedure is applied. This is due to the fact that the solubility error for barium sulphate, for the amounts of sulphur in question and the conditions of precipitation prescribed, is probably the largest one to be considered. Barium sulphate is soluble† in acids and even in pure water, and the solubility limit is reached almost immediately on contact with the solvent. Hence, in the event of using reagents of very superior quality or of exercising more than ordinary precautions, there may be no apparent "blank," because the solubility limit of the solution for barium sulphate has not been reached or at any rate not exceeded.

As shown in the preliminary report,‡ the Atkinson and sodium peroxide methods give results in close agreement with the Eschka method. Regester§ has shown that, if 5 per cent of nitrogen is present in the gases contained in the bomb calorimeter, the sulphur of a coal is almost com-

* *J. Am. Chem. Soc.*, **21** (1899), 1125.
† *Ibid.*, **32** (1910), 588; **33** (1911), 829.
‡ *J. Ind. Eng. Chem.*, **5** (1913), 524.
§ *Ibid.*, **6** (1914), 812.

pletely oxidized to sulphuric acid and the washings of the calorimeter may be used for the determination of sulphur.

The permissible differences in duplicate determinations are as follows:

	Same Analyst	Different Analysts
Sulphur under 2 per cent.....	0.05 per cent	0.10 per cent
Sulphur over 2 per cent	0.10 per cent	0.02 per cent

DETERMINATION OF PHOSPHORUS IN ASH

Method I—To Cover All Cases

To the ash from 5 grams of coal in a platinum capsule are added 10 c.c. of nitric acid and 3 to 5 c.c. of hydrofluoric acid. The liquid is evaporated and the residue fused with 3 grams of sodium carbonate. If unburned carbon is present 0.2 gram of sodium nitrate is mixed with the carbonate. The melt is leached with water and the solution filtered. The residue is ignited, fused with sodium carbonate alone, the melt leached and the solution filtered. The combined filtrates, held in a flask, are just acidified with nitric acid and concentrated to a volume of 100 c.c. To the solution, brought to a temperature of 85°C., is added 50 c.c. of molybdate solution and the flask shaken for 10 minutes. If the precipitate does not form promptly and subside rapidly, add enough ammonium nitrate to cause it to do so. The precipitate is washed six times, or until free from acid, with a 2 per cent solution of potassium nitrate, then returned to the flask and titrated with standard sodium hydroxide solution. The alkali solution may well be made equal to 0.00025 gram phosphorus per cubic centimeter, or 0.005 per cent. for a 5-gram sample of coal, and is 0.995 of one-fifth normal.* Or the phosphorus in the precipitate is determined by reduction and titration of the molybdenum with permanganate.

Note.—The advantage of the use of hydrofluoric acid in the initial attack of the ash lies in the resulting removal of silica. Fusion with alkali carbonate is necessary for the elimination of titanium, which if present and not removed will contaminate the phosphomolybdate and is said to sometimes retard its precipitation.

Method II

When titanium is so low as to offer no objection, the ash is decomposed as under Method I, but evaporation is carried only to a volume of about 5 c.c. The solution is diluted with water to 30 c.c. boiled and filtered. If the washings are turbid they are passed again through the filter. The residue is ignited in a platinum crucible, fused with a little sodium carbonate, the melt dissolved in nitric acid and its solution, if clear, added to the main one. If not clear it is filtered. The subsequent procedure is as under Method I. The fusion of the residue may be dispensed with in routine work on a given coal if it is certain that it is free from phosphorus.

ULTIMATE ANALYSIS

Carbon and Hydrogen

The determination of carbon and of hydrogen is made with a weighed quantity of sample in a 25-burner combustion furnace of the Glaser type.

*Ulmann and Buch, *Chem. Eng.*, **10** (1909), 130.

The products of combustion are thoroughly oxidized by being passed over red-hot copper oxide and lead chromate, and are fixed by absorbing the water in a weighed Marchand tube filled with granular calcium chloride ($CaCl_2$) and by absorbing the carbon dioxide in a Liebig bulb containing a 30 per cent solution of potassium hydroxide (KOH).

The apparatus used consists of a purifying train, in duplicate, a combustion tube in the furnace, and an absorption train. The purifying train consists of the following purifying reagents arranged in order of passage of air and oxygen through them: sulphuric acid, potassium hydroxide solution, soda lime, and granular calcium chloride. One of the trains is for air and one for oxygen. In the sulphuric acid and potassium hydroxide scrubbing bottles the air and the oxygen are made to bubble through about 5 mm. of the purifying reagent. Both purifying trains are connected to the combustion tube by a Y-tube, the joint being made tight by a rubber stopper.

The combustion tube is made of hard Jena glass. Its external diameter is about 21 mm., and its total length is 1 meter. The first 30 cm. of the tube are empty; following this empty space is an asbestos plug (acid-washed and ignited) or in its place a roll of oxidized copper gauze may be used; the next 40 cm. are filled with "wire" copper oxide; a second asbestos plug separates the copper oxide from 10 cm. of fused lead chromate, which is held in place by another asbestos plug 20 cm. from the end of the tube. The end of the tube is drawn out for rubber tubing connection with the absorption train.

The absorption train consists, first, of a Marchand tube filled with granular calcium chloride ($CaCl_2$) to absorb moisture. The $CaCl_2$ should be saturated with CO_2 before using. The Marchand tube is followed by a Liebig bulb containing a 30 per cent potassium hydroxide (KOH) solution, in which any possible impurities, as ferrous iron or nitrites, have been oxidized by a little potassium permanganate ($KMnO_4$). A guard tube, containing granular calcium chloride and soda lime, is attached to the Liebig bulb to absorb any carbon dioxide escaping the potassium hydroxide solution and any water evaporating from that solution.

The train is connected to an aspirator which draws the products of combustion through the entire train. A guard tube of calcium chloride prevents moisture from running back into the absorption train. The suction is maintained constant by a Mariotte flask. The advantage of aspirating the gases through the train rather than forcing them through by pressure is that the pressure on the rubber connections is from the outside, so that gas-tight connections are more easily maintained than if the pressure is on the inside of the tube. The connections are made as tight as possible. The usual test for tightness is to start aspiration at the rate of about three bubbles of air per second through the potash bulb, and then to close the inlet for air and oxygen at the opposite end of the train; if there is no more than one bubble per minute in the potash bulb, the apparatus is considered tight.

Before starting a determination when the train has been idle some hours, or after any changes in chemicals or connections, a blank is run by aspirating about 1 liter of air through the train, which is heated in the same manner as if a determination on coal were being made. If the Liebig bulb and the

tube containing calcium chloride show a change in weight of less than 0.5 mg. each, the apparatus is in proper condition for use.

A porcelain or platinum boat is provided with a glass weighing tube of suitable size, which is fitted with an accurately ground glass stopper. The tube and empty boat are weighed. Approximately 0.2 gram of the air-dry coal (60-mesh and finer, or better, 100-mesh if much free impurity is present) are quickly placed in the boat. The boat is at once placed in the weighing tube, which is quickly stoppered to prevent moisture change in the coal while weighing, and transferring to the furnace. The absorption tubes are connected and the boat and sample are transferred from the weighing tube to the combustion tube, which should be cool for the first 30 cm. The copper oxide should be red hot and the lead chromate at a dull-red heat. The transfer of the boat from weighing tube to combustion tube should be made as rapidly as possible. As soon as the boat is in place near the asbestos plug, at the beginning of the copper oxide, the stopper connecting with the purifying train is inserted and the aspiration started with pure oxygen gas at the rate of three bubbles per second. One burner is turned on about 10 cm. back from the boat, and the aspiration is continued carefully until practically all the moisture is expelled from the sample. The heat is then increased very gradually until all the volatile matter has been driven off. In driving off the volatile matter the heat must be applied gradually in order to prevent a too rapid evolution of gas and tar, which may either escape complete combustion or may be driven back into the purifying train. The heat should be slowly increased by turning on more burners under the open part of the tube until the sample is ignited; then the temperature can be increased rapidly, but care should be taken not to melt the combustion tube. Any moisture collecting in the end of the combustion tube, or in the rubber connection joining it to the calcium chloride tube is driven over into the calcium chloride tube by carefully warming with a piece of hot tile. The aspiration with oxygen is continued for 2 minutes after the sample ceases to glow, the heat is then turned off and about 1,200 c.c. of air are aspirated. The absorption bulbs are then disconnected, wiped with a clean cloth, and allowed to cool to the balance-room temperature before weighing.

$$\text{Per cent hydrogen} = \frac{11.19 \times \text{increase in weight of } CaCl_2 \text{ tube}}{\text{Weight of sample}}$$

$$\text{Per cent carbon} = \frac{27.27 \times \text{increase in weight of KOH bulb}}{\text{Weight of sample}}$$

The ash in the boat is weighed and carefully inspected for any unburned carbon, the presence of which would destroy the value of the determination.

Method with Electrically Heated Combustion Furnace.—An electrically heated combustion furnace of the Heraeus type is used by the Bureau of Mines.*

It consists of three independent heaters, two of which are provided with sheave wheels, and are mounted on a track so that they are movable along the tube; the third heater which surrounds the lead chromate is stationary.

The furnace as provided by the manufacturer does not include the small

*U. S. Bureau of Mines, *Tech. Paper* 8, revised edition 1913, p. 22.

stationary heater. This can be made in the laboratory by winding an alundum tube 12 cm. in length with No. 20 nichrome II wire and enclosing it in a cylinder packed with magnesia-asbestos. The movable heaters have very thin platinum foil, weighing about 9 grams in all, wound on a porcelain tube of 30 mm. internal diameter. The larger one, which heats the copper oxide, is 350 mm. in length, and the smaller one, which heats the sample in the boat, is 200 mm. in length. The Jena glass or fused silica combustion tube of about 21 mm. external diameter and 900 mm. in length, is supported by an asbestos-lined nickel trough. The current through each heater is regulated independently by separate rheostats, mounted on the frame of the furnace. The two platinum-wound heaters require an average current of about 4.5 amperes at a pressure of 220 volts, although for heating rapidly a larger amperage is necessary.

The oxygen or air entering the combustion tube is purified by passing through a Tauber's drying apparatus, which contains the following reagents arranged in order of the passage of air or oxygen through them: sulphuric acid, for removing possible traces of ammonia, 30 per cent potassium hydroxide (KOH) solution, granular soda lime, and granular calcium chloride. One side of the train is connected directly to a Linde oxygen tank, which is provided with a reducing valve for regulating the oxygen pressure; the other side of the train is used for purifying the air supply.

The absorption train consists of a 5-in. U-tube, filled with granular calcium chloride ($CaCl_2$) to absorb moisture. Before using, the calcium chloride should be saturated with carbon dioxide to avoid possible absorption of carbon dioxide during a determination by any traces of calcium oxide that may be present. This saturating is done most conveniently by placing a quantity of calcium chloride in a large drying jar, and filling the jar with carbon dioxide. After standing over night, dry air is drawn through the jar to remove the carbon dioxide. The treated calcium chloride is kept in well-stoppered bottles.

The calcium chloride tube is connected to a Vanier potash bulb containing a 30 per cent potassium hydroxide solution and granular calcium chloride. Six to eight determinations can be made without recharging this bulb. The potash bulb is connected to an aspirator through a guard tube containing granular calcium chloride and soda lime, and a Mariotte flask. The Mariotte flask keeps the pressure constant.

In general, the method of determination is the same as the one used with the gas furnace. By removing the heaters toward the end of the tube where the gases enter, and cutting in the electric current, the air can be warmed enough to dry the tube and its contents thoroughly. The current is then cut off from the small heater, and the large heater is moved over the copper oxide; about 250 mm. of that part of the combustion tube between the two heaters where the boat containing the sample is to be placed is kept exposed. The full current is then turned on the large heater to bring the copper oxide to a red heat. When this temperature is reached it is necessary to reduce the current with the rheostat to avoid melting the tube. In the meantime the absorption train is weighed and connected, and the boat containing the sample is placed in the exposed and cooler part of the tube between the two heaters.

The current is then passed through the shorter heater. By manipulating the rheostat and by gradually pushing this heater toward the boat, the rate of evaporation of moisture and evolution of volatile matter can be readily controlled.

After combustion is complete, the electric current is turned off the smaller heater and this heater moved back to allow the tube to cool for the next determination. The final aspiration of air and the weighing of the absorption train is conducted as described under the gas furnace method.

NOTES.—In place of granulated $CaCl_2$, concentrated sulphuric acid may be used for collecting the water formed by combustion. In such cases the air and oxygen entering the combustion tube and the gas leaving the potash bulb must also be dried by sulphuric acid.

Other suitable forms of absorption vessels than those indicated in the above procedure may be used.

NITROGEN

The Kjeldahl-Gunning method is recommended for the determination of nitrogen. This method has the advantage over either the simple Kjeldahl or the Gunning method, in requiring less time for the complete oxidation of the organic matter, and in giving the most uniform results.

The Kjeldahl-Gunning Method.—One gram of the coal sample is boiled with 30 c.c. of concentrated sulphuric acid (H_2SO_4), 7 to 10 grams of potassium sulphate (K_2SO_4), and 0.6 to 0.8 gram of metallic mercury in a 500-c.c. Kjeldahl flask until all particles of coal are oxidized and the solution is nearly colorless. The boiling should be continued at least 2 hr. after the solution has reached the straw-colored stage. The total time of digestion will be from 3 to 4 hr. The addition of a few crystals of potassium permanganate ($KMnO_4$), after the solution has cooled enough to avoid violent reaction, tends to insure complete oxidation.

After cooling, the solution is diluted to about 200 c.c. with cold water. If the dilution with water has warmed the solution, it should be again cooled and the following reagents added: 25 c.c. potassium sulphide (K_2S) solution (40 grams K_2S per liter) to precipitate the mercury; 1 to 2 grams of granular zinc to prevent bumping; and finally enough strong sodium hydroxide (NaOH) solution (usually 80 to 100 c.c.) to make the solution distinctly alkaline. The danger of loss of ammonia may be minimized by holding the flask in an inclined position while the sodium hydroxide solution is being added. The alkaline solution runs down the side of the flask and forms a layer below the lighter acid solution. After adding the alkaline solution, the flask is at once connected to the condensing apparatus and the solution mixed by gently shaking the flask.

The ammonia (NH_3) is distilled over into a measured amount (10 c.c.) of standard sulphuric acid solution, to which has been added sufficient cochineal indicator for titration. Care should be taken that the glass connecting tube on the end of the condenser dips under the surface of the standard acid. The solution is slowly distilled until 150 to 200 c.c. of distillate have passed over. To avoid mechanically entrained alkali passing over into the condenser, the rate of distillation should not exceed 100 c.c. per hour. The distillate is titrated with standard ammonia solution (20 c.c.

NH_4OH solution = 10 c.c. H_2SO_4 solution = 0.05 gram nitrogen). Standard NaOH or KOH solution with methyl orange or methyl red as indicator may be used instead of ammonia and cochineal.

A blank determination should be made in exactly the same manner as described above, except that 1 gram of pure sucrose (cane sugar) is substituted in place of the coal sample. The nitrogen found in this blank determination is deducted from the result obtained with the coal sample.

The potassium sulphide and sodium hydroxide may be dissolved in a single stock solution. Sufficient potassium sulphide is dissolved in the water before adding the sodium hydroxide, to make a solution in which the quantity necessary for a nitrogen determination (80 to 100 c.c. contains 1 gram of potassium sulphide). Twelve grams of potassium sulphide and 500 grams of sodium hydroxide in 1 liter of water are required for the above proportions.

Coke and anthracite coal should be ground to an impalpable powder, as they are very difficult to oxidize. Even if this is done the digestion may require 12 to 16 hr.

Oxygen

There being no satisfactory direct method of determining oxygen, it is computed by subtracting the sum of the percentages of hydrogen, carbon, nitrogen, sulphur, water and ash from 100. The result so obtained is affected by all the errors incurred in the other determinations and especially by the change in weight of the ash-forming constituents on ignition; iron pyrite changes to ferric oxide, increasing the ash and causing a negative error in the oxygen equivalent to three-eighths of the pyritic sulphur. On the other hand, there is always a loss on ignition, of water of composition from the clayey and shaley constituents, carbon dioxide from carbonates, etc., which tends to compensate the absorption of oxygen.

Corrected Oxygen.—When a more correct oxygen value is desired, it may be obtained by making the corrections indicated in the following formula:

$$\text{Corrected oxygen} = 100 - [(C - C') + (H - H') + N + H_2O + S' + \textit{corrected ash}]$$

in which

C = Total carbon
C' = Carbon of carbonates
H = Total hydrogen—hydrogen of water
H' = Hydrogen from water of composition in clay, shale, etc.
N = Nitrogen
H_2O = Moisture as found at 105°C.
S' = *Sulphur not present as pyrite or sulphate.* (This is usually small and in many types of coal it may be disregarded.)

Corrected ash = mineral constituents originally present in the coal. (For most purposes this can be determined with sufficient accuracy by adding to the ash, as found, five-eighths of the weight of pyritic sulphur, the CO_2 of carbonates and the water of composition of clay, shale, etc. See also *Ash Determination.*)

CALORIMETRIC DETERMINATION

Apparatus

Combustion Bombs.—The Atwater, Davis, Emerson, Mahler, Parr, Peters, Williams, or similar bombs may be used. The bomb shall have an inner surface of platinum, gold, porcelain enamel, or other material which is not attacked by nitric and sulphuric acids, or other products of combustion.

Calorimeter Jacket.—The calorimeter must be provided with a water-jacket having a cover to protect the calorimeter from air currents. The jacket must be kept filled with water within 2 or 3°C. of the temperature of the room (except in calorimeters which are totally submerged, where the jacket temperature is controlled by a thermostat) and should be stirred continuously by some mechanical stirring device.

Stirring of the Calorimeter Water.—The water in the calorimeter must be stirred sufficiently well to give consistent thermometer readings while the temperature is rising rapidly. The speed of stirring should be kept constant. A motor-driven screw or turbine stirrer is recommended and the speed should not be excessive. This may be determined by adjusting the temperature of the calorimeter to equality with that of the jacket and allowing the stirrer to run continuously for 10 min. If the temperature of the calorimeter rises more than about 0.01°C. in this length of time, the rate of stirring is excessive. Accurate results cannot be obtained when too much energy is supplied by the stirring device or when the rate of stirring is irregular. The portion of the stirring device immersed in the calorimeter should be separated from that outside by non-conducting material, such as hard rubber, to prevent conduction of heat from the motor or outside air.

Thermometers.—Thermometers used shall have been certified by a government testing bureau and shall be used with the corrections given on the certificate. This shall also apply to electrical resistance or thermo-electric thermometers. Correction shall also be made for the temperature of the emergent stem of all mercurial thermometers, and for the "setting" of Beckmann thermometers. For accurate work, either Beckmann or special calorimetric thermometers graduated to 0.01 or 0.02°C. are required. Such thermometers should be tapped lightly just before each reading to avoid errors caused by the sticking of the mercury meniscus, particularly when the temperature is falling. A convenient method is to mount a small electric buzzer directly on the top of the thermometer and connect it up with a dry cell and a push button. The button should be pressed for a few seconds immediately before each reading.

Oxygen.—The oxygen used for combustions shall be free from combustible material. The bomb when filled should contain at least 5 per cent of nitrogen to insure complete oxidation of the sulphur.* The total amount of oxygen contained in the bomb for a combustion shall not be less than 5 grams per gram of coal. But the combustion must be complete, as shown by the absence of any sooty deposit on opening the bomb after firing.

Firing Wire.—The coal in the bomb may be ignited by means of either iron or platinum wire. If iron wire is used, it should be of about No. 34 B. & S. gage and not more than 10 cm. (preferably 5 cm.) should be used

*Regester, *J. Ind. Eng. Chem.*, **6** (1914), 812.

at a time. A correction of 1,600 cal. per gram weight of iron wire burned is to be subtracted from the observed number of calories.

Standardization.—The water equivalent of a calorimeter can best be determined by the use of the standard combustion samples supplied by the Bureau of Standards. The required water equivalent is equal to the weight of the sample multiplied by its heat of combustion per gram and divided by the corrected rise in temperature.

The calorimeter shall be standardized by the combustion of standard samples supplied by the Bureau of Standards and used according to the directions given in the certificates which accompany them. A standardization shall consist of a series of not less than five combustions of either the same or different standard materials. The conditions as to the amount of water, oxygen, firing wire, method of correcting for radiation, etc., under which these combustions are made shall be the same as for coal combustions. In the case of any disagreement between contracting parties a check standardization may consist of two or more combustions of standardizing samples.

MANIPULATION

1. *Preparation of Sample.*—The ground sample is to be thoroughly mixed in the bottle and an amount, approximately 1 gram, is to be taken out and weighed in the crucible in which it is to be burned. Coals which are likely to be blown out of the crucible should be briquetted. After weighing, the sample should preferably be immediately placed in the bomb and this closed. This procedure is necessary to avoid sublimation in the use of naphthalene for standardization.

2. *Preparation of the Bomb.*—The firing wire, if iron, should be measured and coiled in a small spiral and connected between the platinum terminals, using, if necessary, a piece of platinum wire somewhat heavier than the iron wire, to make the connection. The platinum and the iron must both be clean. About 0.5 c.c. of water should be placed in the bottom of the bomb to saturate with moisture the oxygen used for combustion. When the crucible is put in place in the bomb, the firing wire should touch the coal or briquette of standard material. For the combustion of standardizing samples iron wire is preferable to platinum.

3. *Filling the Bomb with Oxygen.*—Oxygen from the supply tank is to be admitted slowly to avoid blowing the coal from the crucible, and the pressure allowed to reach 20 atmospheres for the larger bombs or about 30 atmospheres for the smaller bombs, so that the bomb shall contain an amount of oxygen sufficient for complete combustion, namely, at least 5 grams per gram of coal, or other combustible. This method of filling will insure 4 per cent of nitrogen in the larger bombs, irrespective of the nitrogen contained in the oxygen.

4. *Calorimeter Water.*—The calorimeter is to be filled with the required amount of distilled water, depending upon the type of calorimeter. The amount may be determined either by measurement in a standardized flask or by weighing. The amount must be kept the same as that used in standardization of the apparatus.

5. *Temperature Adjustments.*—The initial temperature in the calorimeter should be so adjusted that the final temperature, after the combustion, will not be more than 1°C., preferably about 0.5°C., above that of the jacket,

under which conditions the total correction for heat gained from or lost to the surroundings will be small when the rise of temperature is 2 or 3°C. and the effect of evaporation will also be small.

6. *Firing Current.*—The electric current used for firing the charge should be obtained from storage or dry cells having an electromotive force of not more than 12 volts, since a higher voltage is liable to cause an arc between the firing terminals, introducing additional heat, which cannot be measured with certainty. The circuit should be closed by means of a switch, which should remain closed for not more than 2 sec. When possible, it is recommended that an ammeter be used in the firing circuit to indicate when the firing wire has burned out.

7. *Method of Making an Observation.*—The bomb, when ready for firing, is to be placed in the calorimeter, the firing wires connected, the cover put in place and the stirrer and thermometer so placed as not to be in contact with the bomb or container. The stirrer is then started and after the thermometer reading has become steady, not less than 2 min. after the stirrer is started, temperatures are read at 1-min. intervals for 5 min. and the charge is then fired, the exact time of firing being noted. Observations of temperature are then made at intervals depending upon the method to be used for computing the cooling correction. When the temperature has reached its maximum and is falling uniformly, a series of thermometer readings is taken at 1-min. intervals for 5 min. to determine the final cooling rate.

8. *Titration.*—After a combustion the bomb is to be opened, after allowing the gas to escape, and the inside examined for traces of unburned material or sooty deposit. If these are found, the observations shall be discarded. If the combustion appears complete, the bomb is to be rinsed out thoroughly and the washings titrated with a standard alkali solution (1 c.c. = 0.02173 gram HNO_3 = 5 cal.), using methyl orange or methyl red indicator, to determine the amount of acid formed. A correction of 230 cal. per gram of nitric acid should be subtracted from the total heat observed. An additional correction of 1,300 cal. per gram of sulphur in the coal should be made for the excess of difference in heats of formation of SO_2 and aqueous H_2SO_4 over the heat of formation of aqueous HNO_3.

Computation of Results

The following method of computation is recommended to take the place of the Pfaundler or other similar formulas for computing the cooling correction (radiation correction).

Observe (1) the rate of rise, r_1, of the calorimeter temperature in degrees per minute for 5 min. before firing; (2) the time, a, at which the last temperature reading is made immediately before firing; (3) the time, b, when the rise of temperature has reached six-tenths of its total amount (this point can generally be determined by adding to the temperature observed before firing, 60 per cent of the expected* temperature rise, and noting the time

* When the temperature rise is not approximately known beforehand, it is only necessary to take thermometer readings at 40, 50, 60 sec. (and possibly 70 sec. with some calorimeters) after firing, and from these observations to find when the temperature rise had reached 60 per cent of the total. Thus, if the temperature at firing was 2.135°, at 40 sec. 3.05°, at

when this point is reached); (4) the time, c, of a thermometer reading taken when the temperature change has become uniform some 5 min. after firing; (5) the final rate of cooling, r_2, in degrees per minute for 5 min.

The rate r_1 is to be multiplied by the time $b - a$ in minutes and tenths of a minute, and this product added (subtracted if the temperature was *falling* at the time a) to the thermometer reading taken at the time a. The rate r_2 is to be multiplied by the time $c - b$ and this product added (subtracted if the temperature was *rising* at the time c and later) to the thermometer reading taken at the time c. The difference of the two thermometer readings thus corrected, provided the corrections from the certificate have already been applied, gives the total rise of temperature due to the combustion. This multiplied by the water equivalent of the calorimeter gives the total amount of heat liberated. This result, corrected for the heats of formation of HNO_3 and H_2SO_4 observed and for the heat of combustion of the firing wire, when that is included, is to be divided by the weight of the charge to find the heat of combustoin in calories per gram. Calories per gram multiplied by 1.8 give the British thermal units per pound (see example).

The permissible differences in duplicate determinations are as follows:

Same analyst	Different analysts
0.3 per cent	0.5 per cent

In practice, the time $b - a$ will be found so nearly constant for a given calorimeter with the usual amounts of fuel that b need be determined only occasionally.

The results should be reduced to calories per gram or British thermal units per pound of *dry coal*, the moisture being determined upon a sample taken from the bottle at about the same time as the combustion sample is taken.

Example

Water equivalent = 2,550 grams Weight of charge = 1.0535 grams
Approximate rise of temperature expected = 3.2°
60 per cent of approximate rise = 1.9°

Observations time	Thermometer reading°	Corrected temperature° (or corrected Beckmann thermometer reading) Thermometer corrections taken from the certificate
10–21	15.244	
22	0.250	
23	0.255	
24	0.261	
25	0.266	
26a	0.272	15.276

50 sec. 3.92°, at 60 sec. 4.16°, and the final temperature was 4.200°, the total rise was 2.07°; 60 per cent of it was 1.24°. The temperature to be observed was then 2.14° + 1.24° = 3.38°. Referring to the observations at 40 and 50 sec., the temperatures were respectively 3.05 and 3.92°. The time corresponding to the temperature of 3.38° was therefore.

$$40 + \frac{3.38 - 3.05}{3.92 - 3.05} \times 10 = 44 \text{ sec.}$$

Charge fired		
27.2*b*	17.2*	
31	18.500	18.497
32	0.498	
33	0.497	
34	0.498	
35	0.494	
36	0.493	

COMPUTATION

r_1 = 0.028° ÷ 5 = 0.0056° per minute. $b - a$ = 1.2 min.

The corrected initial temperature is

15.276° + 0.0056° × 1.2 = 15.283°

r_2 = 0.007° + 5 = 0.0014° per minute. $c - b$ = 3.8 min.

The corrected final temperature is

18.497° + 0.0014 × 3.8 = 18.502°

Total rise is 18.502° − 15.283°	= 3.219°	
Total calories 2,550 × 3.219	=	8,209
Titration, etc		− 7
Calories from 1.0535 gram coal		8,202
Calories per gram	7,785	
Or, B.t.u. per pound	14,013	

The result obtained by the above method of computation and determination is the total heat of combustion at constant volume, with the water in the products of combustion condensed to liquid at the temperature of the calorimeter, that is, about 20 to 35°C.

Net heat of combustion at 20° shall refer to results corrected for latent heat of vaporization, as follows:

Total heat of combustion in B.t.u. − 1,040 (per cent hydrogen × 9) = net heat of combustion in B.t.u. per pound.

Also

Total heat of combustion in calories − 580 (per cent hydrogen × 9) = net heat of combustion in calories per gram.

NOTES.—For anthracite, coke and coal of high ash content, which do not readily burn completely, the following procedure is recommended: The inside of the crucible is lined completely with ignited asbestos in a thin layer pressed well down into the angles. The coal is then sprinkled evenly over the surface of the asbestos. Otherwise the procedure is as previously described.

The method of computing the "cooling correction" described in U. S. Bureau of Mines, *Tech. Paper* **8**, p. 28 to 32, may also be used.

*The initial temperature is 15.27°; 60 per cent of the expected rise is 1.9°. The reading to observe is then 17.2°.

APPENDIX II

METHODS FOR TESTING FUEL OILS AND SPECIFICATIONS FOR FUEL OILS

METHODS FOR TESTING FUEL OILS, ADOPTED BY THE COMMITTEE ON STANDARDIZATION OF PETROLEUM SPECIFICATIONS, EFFECTIVE DEC. 29, 1920

Flash-point.—The flash-point of fuel oil shall be determined in the Pensky-Martens closed tester.

The following dimensions are specified for the Pensky-Martens tester:

CUP

Dimension (inches)	Minimum	Normal	Maximum
Inside diameter below filling mark.....	1.950	2.000	2.050
Thickness walls, below filling mark....	0.120	0.125	0.130
Inside height.....	2.150	2.200	2.250
Thickness bottom.....	0.070	0.095	0.120
Distance from rim to filling mark.....	0.855	0.865	0.875
Distance lower surface flange to bottom of cup.....	1.780	1.795	1.810

The inside of the cup may be turned to a slightly larger diameter above the filling mark and the outside may be tapered above the flange but the wall thickness at the upper edge shall not be less than 0.04 in. The flange should be approximately ½ in. wide and should be equipped with devices for locating the position of the lid on the cup and the cup in the stove. A handle attached permanently to the flange of the cup is a desirable accessory.

LID

Stirring Device.—The lid shall be equipped with a stirring device consisting of a vertical shaft mounted in the horizontal center of the cup. The shaft shall carry two two-bladed propellers. The blades of both propellers should be approximately 5/16 in. wide and should be set at an angle of approximately 45°. The smaller (upper) propeller should have an overall diameter of approximately ¾ in. The larger (lower) propeller should have an overall diameter of approximately 1½ in. The plane of the center of the upper propeller shall be 0.4 in. below the level of the rim of the cup. The plane of the center of the lower propeller shall be 2.0 in. below the level of the rim of the cup.

Cover Proper.—The cover proper shall have a rim projecting downward almost to the flange of the cup and fitting the outside of the cup closely. There shall be a proper locating device engaging with a corresponding locating device on the flange of the cup.

There shall be four openings in the lid as indicated in Fig. 382.

Opening *A* is the area defined by arcs of two circles and the intersected lengths of two radii. The radius of the outer circle shall be not less than 0.938 ($^{15}/_{16}$) in. nor more than 0.969 ($^{31}/_{32}$) in. The radius of the inner circle shall be not less than 0.531 ($^{17}/_{32}$) in. nor more than 0.563 ($^{9}/_{16}$) in. The chord of the arc of the outer circle shall be not less than 0.500 ($^{1}/_{2}$) in. nor more than 0.531 ($^{17}/_{32}$) in.

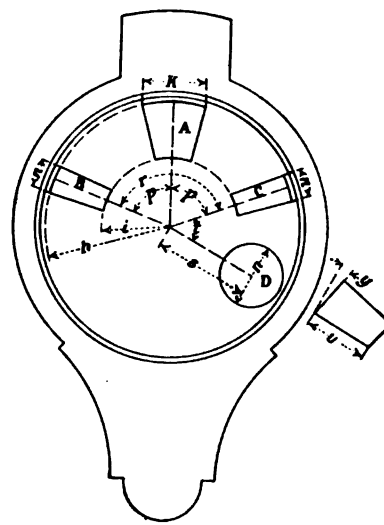


FIG. 382—Pensky-Martens closed tester: *A*, *B*, *C*, *D*, openings in lid; *h*, min. 0.938, max. 0.969 inch; *i*, min. 0.531, max. 0.563 inch; *k*, min. 0.500, max. 0.540 inch; *n*, min. 0.187, max. 0.219 inch; angles *p* equal; angle *r*, min. 135°, max. 140°; *s*, approximately 0.75 inch; angle *t*, min. 50°, max. 60°; *u*, approximately 0.5 inch; angle *y*, min. 10°, max. 15°.

Openings *B* and *C* are equal areas, each of the same general form as opening *A*, but of approximately half the (angular) width. The radii of the inner and outer circles shall be within the limits specified for the radii of the two circles, arcs of which partially define opening *A*. The chord of the outer arc for opening *B* or opening *C* shall be not less than 0.188 ($^{3}/_{16}$) in., nor more than 0.219 ($^{7}/_{32}$) in. Openings *B* and *C* shall be equally distant from opening *A*, and radii drawn through each of their centers shall be at an angle of not less than 135° nor more than 140°.

Opening *D* is for a thermometer collar. Its center is approximately 0.75 ($^{3}/_{4}$) in. from the center of the lid and on a radius at an angle of not less than 50° nor more than 60° from a radius passing through the center of opening *C*. The thermometer collar shall have an inside diameter of approximately

0.5 (1/2) in. It shall be at an angle of not less than 10° nor more than 15° from the perpendicular.

Shutter.—The lid shall be equipped with a shutter operating on the plane of the upper surface of the lid. The shutter shall be so shaped and mounted that it rotates on the axis of the horizontal center of the lid between two stops so placed that when in one extreme position the openings *A*, *B* and *C* of the lid are completely closed and when in the other extreme position these orifices are completely open.

Flame Exposure Device.—The flame exposure device shall have a tip with an opening 0.0275 to 0.0313 in. in diameter. The flame exposure device shall be equipped with an operating mechanism which, when the shutter is in the "open" position, depresses the tip so that the center of the orifice is in the plane of the under surface of the lid proper at a point on the radius passing through the center of the larger opening *A* and 3/8 of the way out from the inner edge of the opening.

A pilot flame for automatic relighting of the exposure flame should be provided.

A bead 5/32 in. in diameter, preferable of some light colored material such as ivory, bone, or porcelain, may be mounted on the lid so that the size of the test flame can be regulated by comparison.

The mechanism operating the shutter should be of the spring type and constructed so that when at rest the shutter shall exactly close the three openings. When operated to the other extreme the three openings in the lid must be exactly open and the tip of the exposure tube in the exact center of the larger opening on the plane of the lower surface of the lid.

STOVE

Heat shall be supplied to the cup by means of a properly designed stove. This stove shall consist of (1) a heating element and (2) a top plate on which the flange of the cup rests.

1. *Heating Element.*—The heating element shall have a cylindrical interior 1.625 (1 5/8) in. to 1.656 (1 21/32) in. deep and with a diameter not less than 0.125 (1/8) in. nor more than 0.156 (5/32) in. greater than the outside diameter of the cup. The heating element may be either a flame heated metal casting or an electric resistance element.

(*a*) If the heating element is a flame heated metal casting it shall be so designed and used that the temperature of bottom and walls is approximately the same. On this account it should not be less than 1/4 in. thick and the flame should not play directly on the bottom but there should be a circular gauze screen, at least 3 in. in diameter, mounted 1/2 to 1 1/2 in. below the lower level of the metal casting.

The casing should be designed so that products of combustion of the flame cannot pass up and come in contact with the cup.

(*b*) If the heating element is of the electric resistance type it shall be constructed so that all parts of the interior surface are heated equally. This necessitates an even distribution of resistance wire over bottom and walls and a method of construction such that heat is given out from the whole core of the resistance element rather than directly from the wire.

(2) *Top Plate.*—The top plate may be of metal or of some material such

as hard asbestos (or Transite) which is a poor conductor of heat. The total distance from the upper surface of plate to the bottom of the heating element shall exceed the distance from the under surface of the flange to the bottom of the cup by not less than 0.063 (1/16) in. nor more than 0.125 (1/8) in.

(*a*) If the top plate is of metal it shall be mounted with an air gap between it and the upper surface of the heating element. The top plate may be attached to the heating element by means of three screws and spacing bushings. The spacing bushings should be of proper thickness to define the air gap, which shall be not less than 0.125 (1/8) in. wide and the bushings shall not be more than 0.375 (3/8) in. in diameter.

(*b*) If the top plate is of material that conducts heat poorly the air gap may be dispensed with. The thickness should be such that the total depth satisfies the dimensional requirement stated above.

THERMOMETER

The thermometer used with the Pensky-Martens tester shall be the same as that specified for the Tag closed tester in the methods for testing burning oils.

The thermometer shall be mounted so that the bottom of the bulb is 1.75 (1 3/4) in. from the under surface of the lid.

FLASH TEST, METHOD OF OPERATION

1. All parts of the cup and its accessories must be thoroughly clean and dry before starting the test. Particular care must be taken to avoid the presence of any gasoline or naphtha used to clean the apparatus after a previous test.

2. The cup shall be filled with the oil to be tested up to the level indicated by the filling mark.

3. The cover shall be placed on the cup and the latter set in the stove. Care must be taken to have the locating devices properly engaged. The thermometer shall be inserted.

4. The test flame shall be lighted and adjusted so that it is of the size of a bead 5/32 in. in diameter.

5. Heat shall be supplied in such degrees that the temperature read on the thermometer increases not less than 9 nor more than 11°F. per minute. The stirrer shall be turned at the rate of from 1 to 2 revolutions per second.

The specified rate of heating need not be maintained during the whole period required to bring the oil from room temperature to flash point, but must be so maintained for a period of at least 3 min. before the flash point is reached. The oil must be stirred at the specified rate during this period but may or may not be stirred during the previous period of heating.

6. Applications of the test flame shall be made when the temperature reaches each even 2°F. mark on the thermometer. The time required for the complete application shall be about one full second, or the time required to pronounce distinctly "one thousand and one."

7. The flash-point is taken as the temperature read on the thermometer at the time of the exposure that causes a distinct flash within the interior of the cup. The true flash must not be confused with a bluish halo that

sometimes surrounds the test flame for the exposures preceding the one that causes the actual flash.

8. The barometric pressure shall be observed and recorded. No corrections shall be made, except in case of dispute when the flash-point figure shall be corrected according to the following rule:

For each inch (25 mm.) below 29.92 in. (760 mm.) barometric reading add 1.6°F. to the flash-point.

For each inch (25 mm.) above 29.92 in. (760 mm.) barometric reading subtract 1.6°F. from the flash-point.

Water and Sediment. Apparatus.—One hundred cubic centimeters B.S.-tube, graduated in 200 parts. The body of the tube shall be in the form of an inverted cone ending in a sediment tube not less than $\frac{3}{16}$ in. internal diameter. The lowest two intervals shall be subdivided into 0.1 c.c. A laboratory centrifuge, 1,200 to 1,500 r.p.m.

Benzol.—Commercial, water-white, 90 per cent. benzol.

Method.—Measure 50 c.c. of benzol into the B.S.-tube, then add 50 c.c. of the oil to be tested. Shake the tube thoroughly and heat in a water bath to a temperature of 122°F. Again shake thoroughly, and revolve in centrifuge for 5 min. Read percentage of sediment and water. Replace the tube in centrifuge and revolve again for 5 min. Repeat the 5-min. revolutions until a constant reading is obtained. Calculate as per cent. by volume of combined water and sediment.

Carbon Residue.—This test shall be made according to the method specified in the Methods for Testing Lubricants.

Precipitation Test.—This test shall be made according to the method specified in the Methods for Testing Lubricants.

Viscosity. 1. *Apparatus.*—Saybolt Furol Viscosimeter. The dimensions of this instrument are the same as those of the Saybolt Universal Viscosimeter specified below (2*b*), with the following exceptions:

The diameter of the outlet tube shall be as follows:

	Minimum cm.	Normal cm.	Maximum cm.
Inside diameter of outlet tube.....	0.313	0.315	0.317
Outside diameter of lower end.....	0.40	0.43	0.46

2. (*a*) The Saybolt standard universal viscosimeter (see Fig. 383) is made entirely of metal. The standard oil tube *A* is fitted at the top with an overflow cup *B*, and the tube is surrounded by a bath. At the bottom of the standard oil tube is a small outlet tube through which the oil to be tested flows into a receiving flask, Fig. 383, whose capacity to a mark on its neck is 60 ($\pm$0.15) c.c. The lower end of the outlet tube is enclosed by a large tube, which when stoppered by a cork, *C*, acts as a closed air chamber and prevents the flow of oil through the outlet tube until the cork is removed and the test started. A looped string may be attached to the lower end of the cork as an aid to its rapid removal. The temperatures in the standard oil tube and in the bath are shown by thermometers. The bath may be heated by any suitable means. The standard oil tube shall be thoroughly cleaned, and all oil entering the standard oil tube shall be strained through a 60-mesh wire strainer. A stop watch shall be used for taking the time of

flow of the oil and a pipette shall be used for draining the overflow cup of the standard oil tube.

(*b*) The standard oil tube, which may be standardized by the U. S. Bureau of Standards, Washington, D. C., shall conform to the following dimensions:

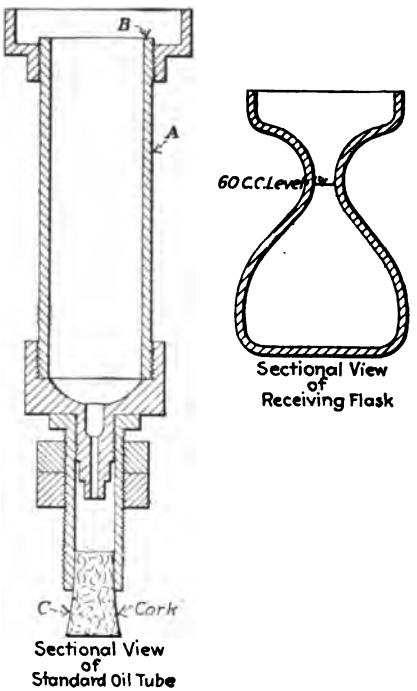


FIG. 383.—Apparatus for use in the determination of viscosity. Left, Saybolt standard universal viscosimeter; *a*, standard oil tube; *b*, overflow cup, *c*, cork stopper. Right, sectional view of receiving flask of Saybolt universal viscosimeter.

Dimensions	Minimum cm.	Normal cm.	Maximum cm.
Inside diameter of outlet tube	0.1750	0.1765	0.1780
Length of outlet tube	1.215	1.225	1.235
Height of overflow rim above bottom of outlet tube	12.40	12.50	12.60
Diameter of container of standard oil tube	2.955	2.975	2.995
Outer diameter of outlet tube at lower end	0.28	0.30	0.32

3. Viscosity of fuel oils shall be determined at either 70°F. (21.1°C.) or 122°F. (50°C.). The bath shall be held constant within 0.25°F. (0.14°C.) at such a temperature as will maintain the desired temperature in the standard oil tube. Oil or water may be used as the bath liquid. Viscosity

determinations shall be made in a room free from draughts, and from rapid changes in temperature. All oil introduced into the standard oil tube, either for cleaning or for test, shall first be passed through the strainer.

To make the test, heat the oil to the necessary temperature and clean out the standard oil tube. Pour some of the oil to be tested through the cleaned tube. Insert the cork stopper into the lower end of the air chamber at the bottom of the standard oil tube, sufficiently to prevent the escape of air, but not to touch the small outlet tube of the standard oil tube.

Heat the oil to be tested, outside the viscosimeter, to slightly below the temperature at which the viscosity is to be determined and pour it into the standard oil tube until it ceases to overflow into the overflow cup. By means of the oil tube thermometer keep the oil in the standard oil tube well stirred and also stir well the oil in the bath. It is extremely important that the temperature of the bath be maintained constant during the entire time consumed in making the test. When the temperature of the bath and of the oil in the standard oil tube are constant and the oil in the standard oil tube is at the desired temperature, withdraw the oil tube thermometer; quickly remove the surplus oil from the overflow cup by means of a pipette so that the level of the oil in the overflow cup is below the level of the oil in the tube proper; place the 60-c.c. flask in position so that the stream of oil from the outlet tube will strike the neck of the flask so as to avoid foam. Snap the cork from its position, and at the same instant start the stop watch. Stir the liquid in the bath during the run and carefully maintain it at the previously determined proper temperature. Stop the watch when the bottom of the meniscus of the oil reaches the mark on the neck of the receiving flask.

The time in seconds for the delivery of 60 c.c. of oil is the Saybolt viscosity of the oil at the temperature at which the test was made.

Sulphur.—Approximately 1 gram of oil is weighed into the calorimeter cup and placed in the bomb, which contains 20 c.c. of distilled water. The purpose of the water is to absorb the sulphur trioxide formed from the oxidation of the sulphur, converting it to sulphuric acid. The ignition wire is attached to the terminals of the bomb, the center of the wire dipping into the oil. Fine platinum wire should be used for this purpose. The bomb is then closed and oxygen introduced up to a pressure of 400 lb. per square inch. When this pressure is obtained, the valve of the bomb is closed and the charge is ignited. From 10 to 15 min. is allowed to elapse for the complete combustion of the oil. The gas in the bomb, after complete combustion has taken place, is allowed to slowly escape.

When the gas in the bomb has been reduced to atmospheric pressure the bomb is opened and the inside rinsed with distilled water, collecting the washings in a beaker. The solution is then made alkaline, either with ammonium hydroxide or sodium carbonate solution, and heated to completely precipitate any heavy metals, and then is filtered. The filtrate is then acidified with hydrochloric acid, heated to boiling, and barium chloride is added drop by drop until an excess of the precipitant is present. The solution is then allowed to stand for two hours on the hot plate to obtain complete precipitation of the barium sulphate. The precipitate is then filtered, washed, dried, ignited and weighed as barium sulphate.

SPECIFICATIONS FOR FUEL OILS

FUEL OIL FOR DIESEL ENGINES

General.—1. This specification covers the grade of oil used by the United States Government and its agencies as a fuel for Diesel engines.

2. Fuel oil shall be a hydrocarbon oil, free from grit, acid, and fibrous or other foreign matters likely to clog or injure the burners or valves. If required, it shall be strained by being drawn through filters of wire gauze of 16 meshes to the inch. The clearance through the strainer shall be at least twice the area of the suction pipe, and the strainers shall be in duplicate.

Properties and Tests.—3. Flash point: The flash point shall not be lower than 150°F. (Pensky-Martens closed tester).

4. Water and sediment: Water and sediment combined shall not amount to more than 0.1 per cent.

5. Carbon residue: The carbon residue shall not exceed 0.5 per cent.

6. Precipitation test: When 5 c.c. of the oil is mixed with 95 c.c. of petroleum ether and allowed to stand 24 hr., it shall not show a precipitate or sediment of more than 0.25 c.c. (5 per cent by volume of the original oil).

All tests shall be made according to the methods for testing fuel oils adopted by the Committee on Standardization of Petroleum Specifications.

FUEL OIL (NAVY STANDARD)

General.—1. This specification covers the grade of oil used by the United States Government and its agencies where a high-grade fuel oil is required.

2. Fuel oil shall be a hydrocarbon oil, free from grit, acid and fibrous or other foreign matters likely to clog or injure the burners or valves. If required, it shall be strained by being drawn through filters of wire gauze of 16 meshes to the inch. The clearance through the strainer shall be at least twice the area of the suction pipe, and the strainers shall be in duplicate.

Properties and Tests.—3. Flash point: The flash point shall not be lower than 150°F. (Pensky-Martens closed tester). In case of oils having viscosity greater than 30 sec. at 150°F. (Saybolt furol viscosimeter) (8° Engler) the flash point shall not be below the temperature at which the oil has a viscosity of 30 sec.

4. Viscosity: The viscosity shall not be greater than 140 sec. at 70°F. (Saybolt Furol Viscosimeter) (40° Engler).

5. Sulphur: Sulphur shall not be over 1.5 per cent.

6. Water and sediment: Water and sediment combined shall not amount to over 1.0 per cent.

All tests shall be made according to the methods for testing fuel oils adopted by the Committee on Standardization of Petroleum Specifications.

BUNKER FUEL OIL "A"

General.—1. This specification covers the grade of fuel oil used by the United States Government and its agencies where a low viscosity oil is required.

2. Fuel oil shall be a hydrocarbon oil, free from grit, acid, and fibrous or other foreign matters likely to clog or injure the burners or valves. If required, it shall be strained by being drawn through filters of wire gauze

of 16 meshes to the inch. The clearance through the strainer shall be at least twice the area of the suction pipe, and the strainers shall be in duplicate.

Properties and Tests.—3. Flash point: The flash point shall be not lower than 150°F. (Pensky-Martens closed tester). In case of oils having viscosity greater than 30 sec. at 50°F. (Saybolt furol viscosimeter) (8° Engler), the flash point shall not be below the temperature at which the oil has a viscosity of 30 sec.

4. Viscosity: The viscosity shall not be greater than 140 sec. at 70°F. (Saybolt Furol Viscosimeter) (40° Engler).

5. Water and sediment: Water and sediment combined shall not amount to over 1.0 per cent.

All tests shall be made according to the methods for testing fuel oils adopted by the Committee on Standardization of Petroleum Specifications.

BUNKER FUEL OIL "B"

General.—1. This specification covers the grade of fuel oil used by the United States Government and its agencies where a more viscous oil than Bunker Oil "A" can be used.

2. Fuel oil shall be a hydrocarbon oil, free from grit, acid, and fibrous or other foreign matters likely to clog or injure the burners or valves. If required, it shall be strained by being drawn through filters of wire gauze of 16 meshes to the inch. The clearance through the strainer shall be at least twice the area of the suction pipe, and the strainers shall be in duplicate.

Properties and Tests.—3. Flash point: The flash point shall be not lower than 150°F. (Pensky-Martens closed tester).

4. Viscosity: The viscosity shall not be greater than 100 sec. at 122°F. (Saybolt Furol Viscosimeter).

5. Water and sediment: Water and sediment combined shall not amount to over 1.0 per cent.

All tests shall be made according to the methods for testing fuel oils adopted by the Committee on Standardization of Petroleum Specifications.

BUNKER FUEL OIL "C"

General.—1. This specification covers the grade of fuel oil used by the United States Government and its agencies where a high viscosity oil is satisfactory.

2. Fuel oil shall be a hydrocarbon oil, free from grit, acid, and fibrous or other foreign matters likely to clog or injure the burners or valves. If required, it shall be strained by being drawn through filters of wire gauze of 16 meshes to the inch. The clearance through the strainer shall be at least twice the area of the suction pipe, and the strainers shall be in duplicate.

Properties and Tests.—3. Flash point: The flash point shall be not lower than 150°F. (Pensky-Martens closed tester).

4. Viscosity: The viscosity shall not be greater than 350 sec. at 122°F. (Saybolt Furol Viscosimeter).

5. Water and sediment: Water and sediment combined shall not amount to over 1.0 per cent.

All tests shall be made according to the methods for testing fuel oils adopted by the Committee on Standardization of Petroleum Specifications.

INDEX

A

Air separators, 578, 602
Alcohol as motor fuel, **1204**
 synthetic, 510
Allis-Chalmers' dryer, 566
Animal traction *vs.* automotive power, 290
Anthracite, briquetting, 236, 282
 cleaning of, 612
 in gas producers, **932**
 industry, 277
 sizes for burning, **669**
 slush, 595
 standard sizes, 279
Anthra-coal, 282
Amalgamation of hydrocarbons, **633**
 with oil, **629**
Ammonia from by-product coke, 191
 manufacture of concentrated, 204
 recovery, direct process, 198
 indirect process, 192
 Koppers direct process, 202
 Semet-Solvay direct process, 200
 stills, 195
Ammonium sulphate, yield from coal, 353
Apparatus for recovery of by products from coal gas, 191
Artificial gas industry, future of, **1095**
 demand rate, **1104**
 early methods, **1095**
 future of, **1105**
 gas for industrial purposes, **1097**
 peak load, **1096**
 relation to coal fields, **1099**
 selling rates, **1104**
Artificial standards of gas quality, **1099**
 types of gas used, **1101**
Arrowhead coal conveyor, **641**
Ash of coke, 108
 effect of, 608
Assay furnaces, pulverized fuel, 555
Atomizers, fuel oil, **834**
Automobile industry, producer gas, **982**
Automotive power *vs.* animal traction, 290

B

Beehive ovens, 134
Benzol from by-product ovens, 187
Benzols, recovery of, 205
Binders, 248
 briquetting, 248
 hydrocarbon, 250
 sodium silicate, 255
 sulfite pitch, 254
Bituminous coal, 3, 6
 briquetting, 238, 268
 in gas producers, **937**
 briquetting of, 288
 economical utilization, 283
 recovery of hydrocarbon, 285
 utilization on multiple product basis, 284
Blast furnace gas,
 cleaning, **1024**
 composition of, **1022**
 dry filter, **1026**
 dust catcher, **1024**
 final cleaning, **1030**
 physical and chemical properties of, **1023**
 principles of production, **1017**

Blast furnace gas, primary cleaning, **1025**
reactions in hearth and bosh, **1018**
in stack **1019**
source of dust, **1022**
of moisture, **1021**
spray tower, **1028**
surplus produced, **1023**
types of final cleaners, **1030**
uses of cleaned, **1029**
uses of raw, **1025**
volume and value of, **1022**
wet primary cleaning, **1027**
whirlers, **1026**
Boiler, Bonecourt, 387
flue gases, recovery of heat from, 391
Boilers, fired with pulverized coal, **675**
American Locomotive Works, **678**
baffling of, **693**
Bethlehem Steel Co., **707**
Bettington, **675**
Erie City Iron Works, **678**
Ford Motor Co., **704**
Fuller-Lehigh System, **695**
Holbeck system, **701**
Lopulco system, **701**
Milwaukee Elec. Railroad & Light Co., **705**
Pulverized Fuel Equipment Co., **701**
Quigley system, **700**
steam locomotives, **681**
Tests on Hanna system, **698**
firing with finely divided fuel, **665**
fuel oil under, **844**
gas fired, 386
Bonnet dryer, 564
Box car coke loader, 178
Bradford breaker, 163
Briquets, 227
peat, 384
Briquetting of bituminous coal, 238, 268, 288
Briquetting, of anthracite, 236, 282
binders, 248
of charcoal, 239
of coke breeze, 239
plant cost, 256
costs of manufacture, 258
of lignite, 240
of peat, 239, 384
present outlook, 231
processes of, 232
of sawdust, 787
Buckeye dryer, 566
Built-in producers for heating by-product coke ovens, 182
Burners, feeders and mixers, pulverized fuel, 647
fuel oil, **832**
marine oil, **858**
By-products, ammonia and cyanogen from, 191
apparatus for recovery from coal gas, 191
benzol, 187
coal preparation, 162
coke, ammonia, 191
characteristics, 92
composition, 188
coke handling system, 175
coke oven construction, 157
collecting main operation, 169
construction, 157–160
examination of coal, 157
dimensions of, 158
door luting, 174
examination for by-product gas production in by-product coke ovens, 151
gas, annual consumption, 180
oven, 145
preparation for by-product coke oven, 162
preparation of coal, 158
pushing, 170
quenching, 173
rate of coking, 159
separation, 170

By-products, gas producers, **969**
use of carbonized fuels, 484
oils, crude fractionation, 209
washing and rectification, 210
ovens, 134
Providence Gas Co., 184
plants, economic size of, 362
power plants, economic location of, 512
producer plants, 359
recovery, 185
expansion, **1161**
from producer gas, costs, **973**
yields of, 185
recuperative ovens, heating with producer gas, 184

C

Calorific value of coke, 114
Cannel coal, 7
Carbocoal, 441
Ammonia, 465
analysis of, 445
briquetting, 462
costs, 456
creosote oils from, 451
flotation oils from, 451
gas, 464
light oil, 466
plant at Clinchfield, Va., 459
coal handling in, 462
primary retorts, 462
properties of, 447
secondary retorts, 463
tar from, 448, 465
tar oils from, 450
yields of products, 453, 454
Carbonization, low temperature, 397, 417
Bussey process, 434
carbocoal, 441
character of coke, 421
of tar oils, 422
comparison with high temperature, 417
continuous processes, 401
Doherty Process, 433
Carbonization, European processes, 402
experiments of Loomis, 421
gas producer retorts, 428
Green-Laucks process, 446
Denver plant, 469
fixed gas, 475
products, 476
retorts, 467
rotary retorts, 437
semi-coke, 471
tar-oils and ammonia, 473
Carbonized fuels, use in by-product gas producers, 484
Carbureted water gas, **1007**
Carnot cycle, 325
Centralized power systems, **1160**
Central power plant, power and heat in, 326
improving the load factor, 327
transportation for, 310
utilization of coal, 309, 316
Chance sand flotation process, 622
Charcoal, briquetting, 239
in gas producers, **932**
Chemical products from petroleum, **1207**
Cleaning blast-furnace gas, **1024**
anthracite, 612
producer gas from high volatile fuels, **946**
from low volatile fuels, **945**
Closed circuit grinding, 593
Coal, analyses of representative, 36, 38
analysis methods, **1214**
areas of U. S., 11
district, 11
Eastern province, 14
field, 12
Gulf province, 14
Interior province, 17
Northern Great Plains province, 20
Pacific coast province, 31
region, 13
Rocky Mountain province, 24
briquetted, 224

Coal, carbonization, 397
with producer gas, 989
chemistry of, 403
cleaning, 608
for further preparation, 613
electrostatic process, 614
Huff electrostatic separator, 615
coking, 82
compression for by-product ovens, 166
constitution of, 402
current demand, **1144**
distillation, history, 395
low temperature, 395
Parker process, 396
examination for by-product coke oven construction, 157
fields, relation of artificial gas, **1099**
flotation, **1170**
mechanical preparation of pulverized, 557
mixing, 165
origin of, 403
physical structure of, 405
pipe lines, 312
preparation for by-product coke oven, 158, 162
products industries, present status, 277
pulverization hammer mill, 164
pulverized, 515
air separation, 578
control of fineness, 577
conveying, **636**
Arrowhead system, **641**
Fuller-Kinyon system, **641**
Heyl & Patterson low-pressure system, **647**
Holbeck high-pressure system, **638**
low-pressure system, **647**
Kennedy-Van Saun low pressure system, **647**
pneumatic mass, **637**
Quigley high-pressure system, **638**
screw, **636**
Coal, history, 516
industrial uses of, 515
assay furnaces, 555
continuous heating furnaces, 533
copper blast furnaces, 544
copper installation, 542
copper smelting, 538
costs of melting metals, 536
drying, 523
forging furnaces, 525
iron blast furnace, 554
lead smelting, 554
malleable iron melting furnaces, 533
melting, 544
metallurgical furnaces, 524
nickel smelting, 540
ore roasting, 522
open-hearth steel furnaces, 529
Quigley system, 528
rotary kilns, 520
sheet mill furnaces, 527
steam boilers, 518
use of low volatile fuels, 523
zinc and tin, 555
mechanical preparation, 557
Allis-Chalmers dryer, 566
Bonnet dryer, 564
Buckeye dryer, 566
commercial types of dryers, 564
Cummers dryer, 567
drying, 561
dust retrieving, 568
externally heated dryers, 567
fuel handling, 560
fuel required for drying, 568
Fuller-Lehigh dryer, 567
granulation and crushing, 558
internally heated dryers, 566
Kennedy-Van Saun dryer, 567
pulverized, magnetic separators, 570

Coal, methods for drying, 564
moisture content, 562
pneumatic conveying, 559
Ruggles-Coles dryer, 565
storage systems, 561
temperature control in drying, 568
washing processes, 618
Chance sand flotation process, 622
coal jigs, 619
concentrating, 620
Dorr, 618
hindered settling methods, 619
inverted cone, 619
limitations of, 620
location of plant, 626
Pulverizing, anthracite slush, 595
bituminous, 596
carbonized fuels, 575
cost of, 604
methods of, 573
screen test, 576
theory of, 571
Coal, Ranks of, 1
anthracite, 4
bituminous, 3, 6
cannel, 7
comparison, 10
lignite, 9
semi-anthracite, 5
semi-bituminous, 3, 8
refinement and economic value, 291
research, history, 406
Parr and Olin, 411
Parr's work, 407
resources of the United States and Canada, 268
rewashing, 1172
storage and charging, 167
utilization in central power plants, 309, 316
vs. fuel oil, **800**
washer waste, 1169
waste, cost, 1149
yield of ammonium sulphate, 353
Coke, action of carbon dioxide on, 114
adaptation to domestic appliances, 415
ash, 108
beehive oven, 131
in the blast furnace, 117
blast furnace screening practice, 175
breeze, 124
burning coke breeze, 125
by-product ovens, 134, 145
calorific value, 114
character, 421
characteristics of by-product, 92
conveyors, 178
crushing strength, 103
domestic, 123
effect of heating on coal, 87
explanation of formation, 89
foundry and domestic screening practice, 176
as a fuel, 115
in gas producers, 933
history of, 128
horizontal flue oven, 136
in the iron foundry, 122
loader, box car, 178
moisture, 108
nitrogen, 110
phosphorus, 109
physical characteristics, 99
relation to analysis, 85
relation to coal, 82
resistance to impact and abrasion, 104
sampling, 213
specific gravity, 100
sulphur in, 111
testing, 212
vertical flue oven, 142
volatile matter of, 107
for water gas manufacture, 142
Coking, preparation of coal, 611
resins, 404
tests, 413
Colliery refuse as fuel, 365
Colloidal fuel, **880, 1163**
fixateurs, **889**

Colloidal fuel, method of burning, **893**
nature of oils used, **893**
protective colloids, **884**
rate of settling, **883**
result of steam tests, **895**
saving due to, **900**
size of colloidal particles, **881**
stability of, **891**
Stokes' law, **882**
use in vessels, **885**
on land, **886**
particles, size of, **881**
Combustion, 44
air and, 61
air in, 44
required for, 64
complete, 63
data from gas analysis, 66
density, weight and volume of gases, 49
flame, 59
heat of, 50
losses, 72
perfect, 63
principles of, 44
products of, 65
specific heat of gases, 53
smoke, 77
temperature, 46
developed in, 56
volume and weight of air, 48
Concentrating coal, 620
Conservation of fuels, 267
Consumption of pulverized coal, 556
Continuous heating furnaces, use of pulverized fuel, 527
Conveying by screw, **636**
in suspension, **645**
of coal, pneumatic, 559
pneumatic mass, **637**
Copper installation, use of pulverized fuel, 542
refining, 544
blast furnace, 544
melting, 544
smelting, use of pulverized fuel, 538
Creosote oils from carbocoal, 451
present sources of, 507
Crushing strength of coke, 103
Cummers' coal dryer, 567
Cyanogen from by-product coke, 191

D

Dayton gas, **1036**
apparatus required, **1039**
chemical properties, **1040**
cost, **1042**
description of apparatus, **1042**
heat balance, **1040**
limits of B.t.u. value, **1037**
method of manufacture, **1038**
physical properties, **1040**
scrubbing, **1046**
tar, **1041**
Diesel engine, 294
Domestic fuel, 481
gas and solid fuel, 482
Draft gages, fuel oil, **861**
Dryers, commercial types, 564
internally heated, 564
Drying, coal, 561
methods, 564
fuel required, 568
pulverized fuel, 523
temperature control, 568
Dry filter, blast furnace gas, **1026**
Dust, catcher, blast furnace gas, **1024**
extractors, 603
retrieving, 568
source in blast furnace gas, **1122**

E

Economics of American power practice, **1135**
coal *vs.* water power, **1137**
cost of coal waste, **1149**
current demand for coal, **1144**
inefficiency of coal utilization, **1146**
super-power stations, **1143**
transmission of electric power, **1143**
water power cost, **1139**
development, **1138**

Electrical industrial heating, 301
Electric furnace, hearth type, **1130**
furnaces, 301
heating, 307
advantages, **1128**
Electricity and fuels, 290
Electric *vs* fuel fire furnaces, **1122**
advantages of electric heating, **1128**
efficiency at different temperatures, **1124**
electric baking-ovens, **1129**
carbonizing furnaces, **1132**
fuel cost and heating cost, **1133**
hearth type electric furnace, **1130**
heat available at different temperatures, **1126**
loss in flue gases, **1123**
radiation losses, **1123**
power transmission, 314
Electrification of railroads, 297, **1157**
Electrostatic process, 614
Engine, Diesel, 294
Engines, internal combustion, 321

F

Fineness, control of, 577
Fixateurs, **889**
Flotation oils from carbocoal, 451
Flue gases, **1123**
Flue gases, boiler, 391
Forge work, producer gas, **987**
Forging furnaces, use of pulverized fuel, 525
Fuel, briquetted, 224
carbonized, 306
colliery refuse, 365
colloidal, **880**
compressed, 224
conservation, **1151**
bituminous coal distribution, **1155**
boiler furnace efficiency, **1154**
Fuel, centralized power systems, **1160**
distribution of coal consumption, **1154**
electrification of railroads, **1157**
expansion of by-product recovery, **1161**
industrial heating furnaces, **1156**
methods, **1153**
railway locomotive operation, **1156**
waste heat boilers, **1157**
domestic, 305
efficient combustion of, 318
finely divided, for firing boilers, **665**
granulated, **665**
in marine boilers, **665**
in stationary boilers, **667**
handling, 560
for industrial furnaces, 299
prepared, tonnage in U. S., 278
vs. raw, 286
prime movers, 319
problems in the utilization, **1165**
flotation of coal, **1170**
glass industry, **1185**
iron and steel industry, **1187**
oil in oil shales, **1176**
refractories industry, **1184**
rewashing of coal, **1172**
shallow piling, **1173**
utilization of coal washer waste, **1169**
of low grade, **1165**
pulverized, possibilities for central stations, **737**
base loads, **752**
combustion control, **751**
effect on station economy, **743**
of variable load, **739**
of intermittent load, **739**
investment required, **751**
range of fuels, **739**
relative power requirements, **737**

Fuel, railway, 296
resources, limitations of, 274
selection, factors, 1114
steamship, 292
storage, 510
utilization of low grade, 317
utilization on a multiple product basis, 317
Fuel oil, advantages, 798
atomizers, 834
Babcock and Wilcox type boiler, 845
burners, 832
carbon dioxide instruments, 861
chimneys, 857
definition, 796
distributing stations in Canada, 878
in U. S., 877
draft gages, 861
efficiency, 804
feeding to burners, 815
furnaces, 842
Heine type boiler, 845
marine oil burners, 858
operating accessories, 861
piping system, 819
purchase, 806
regulation, 803, 808
rules and requirements for storage, 870
soot blowers, 861
specifications, 1242
stack thermometer, 864
Sterling boiler, 847
storage, 802
substitutes, 1205
testing methods, 1235
transportation, 802
transfer, 812
unloading, 810
use under boilers, 844
utilization, 794
vs. coal, 800
Fuller-Kinyon coal conveyor, 641
Fuller-Lehigh coal dryer, 567
Furnace, proper selection, 1114
continuous type, 1111
Furnace, electric, 301
for fuel oil, 842
Fushun colliery plant, 360

G

Gas, annual consumption of by-product coke gas, 180
application of Mond to industrial furnaces, 352
artificial, 1095
blast furnace, 1016
by-product coke oven gas, B.t.u. value, 181
cleaning, 1024
compressed, 501
customer-demand charge, 494
engineering vs. steam engineering, 915
for domestic heating, 482
for general distribution, 489
in Great Britain, 496
for high uses, 330
for low uses, 329
mixed from coal distillation products, 498
properties of, 493
rate for, 494
and solid fuel, 482
standards of quality, 491
as substitute for all other fuels, 490
Gas, natural, 902
chemistry of, 903
combustion of, 904
consumption in industries, 910
cost of, 910
declining supply, 907
enrichment of other gases with, 911
for domestic use, 906
growth of industry, 903
heat value of, 904
mixed with other gases, 908
removal of gasoline from, 905
source of, 902
specific gravity, 904
state of industry, 909
value, 909
weight, 904

Gases, combustion products from, **1053**
B.t.u. available at various temperatures, **1054**
values, **1052**
composition of, **1052**
effect of varying amounts of air, **1063**
thermal capacities, **1051**
Gasification of coal without dilution, 371
external heating, 372
internal heating, 371
of low grade fuel, 364
of pulverized fuel, 372
of peat, 383
Gasoline, removed from natural gas, **905**
substitutes, **1202**
Gas producer,
agitating fuel bed, **925**
blasting, **925**
built in producer, **927**
by-product, **969**
charcoal in, **932**
classification, **921**
coke in, **933**
detarring, **924**
double zone producer, **922**
downdraft producers, **921**
freak producers, **930**
horizontal rotary, 366
lignite in, **937**
mechanical charging, **927**
improvements, **929**
peat in, **937**
series producers, **924**
water cooling, **928**
wet and dry bottom, **929**
production in by-product coke oven, 151–179
quality, standards, **1099**
types used, **1101**
Glass industry, use of lowgrade fuels, **1185**
Granulated fuel, **665**
Granulation and crushing of coal, 558
Grate, pyramid, **673**
Grate, McClave, **673**
Mechanicville, **673**
Grinding, open circuit, 593

H

Hammer mill, 164
Heat application, **1107**
continuous type furnaces, **1111**
efficient operation, **1118**
factors governing fuel selection, **1114**
heat treatment of steel, **1120**
influence of furnace design on cost, **1116**
in small forge furnace, **1112**
proper selection of furnace, **1114**
soaking heats, **1117**
to wire, **1113**
uniform chamber temperature, **1110**
uniformly heated product, **1110**
Heating, cost and fuel cost, **1133**
electric, 307
plants, 308
Heat pump, 304
utilizing low temperature, 391
Heyl & Patterson coal conveyor, **647**
Hilgenstock, Otto, by-product coke oven, 145
Holbeck coal conveyor, **638, 646**
Huff electrostatic separator, 615
Hydrocarbon, 250
recovery from bituminous coal, 285

I

Industrial steam, 297
Iron blast furnace, pulverized fuel, 554
and steel industry, use of lowgrade fuels, **1187**

J

Jigs, coal, 619

K

Kennedy-Van Saun coal conveyor, **647**
dryer, 567
Kilns, rotary, use of pulverized fuel, 520
Koppers ammonia recovery process, 202
by-product coke oven, 147

L

Lead smelting, pulverized fuel, 554
Light oil, recovery, 206
Lignite, 9
briquetting, 240
carbonization of, 477
products, 478
in gas producers, **937**
Lignites, analysis of American, 356
boiler tests with, **696**
use of in Mond plants, 357
Load factor, central power plant, 327
Low temperature distillation of coal, 394
volatile fuel, pulverized, 523
Lymn plant, chemistry of process, 347
description of, 344
operation of, 346

M

Magnetic separators, 165, 570
Malleable iron melting furnaces, use of pulverized coal, 533
Metallurgical furnaces, use of pulverized fuel, 524
Methane, synthetic, 377
Methods for testing fuel oils, **1235**
for the analyses of coal, **1214**
Mills, disc, 583
high-speed pulverizers, 580
ring roll, 583
waste, wood, **786**
Moisture content of coal, 562
in coke, 108
source, in blast-furnace gas, **1021**
Mond process, 331
Motor fuels, 493, 509

N

Natural gas, **902**
Nickel smelting, use of pulverized fuel, 540
Nitrogen content of eastern coals, 354
of western coals, 355
in coke, 110
recovery from bituminous coal, 286

O

Oil for ships' fuel, 295
shales, **1174**
retorts, **1178**
Open-hearth steel furnaces, use of pulverized fuel, 529
Ore roasting, use of pulverized fuel, 522
Origin of coal, 403

P

Parr's work, 407
Parr and Olin, 411
Peak load, artificial gas, **1096**
Peat, briquetting, 239
briquets, 384
briquetting and distillation, 384
economic limitations, 385
excavation and drying, 378
Ekenberg process, 383
gasification, 383
in gas producers, **937**
installation in Scotland, 382
Mond gas from, 358
products, 382
wet carbonization, 380
Phosphorus in coke, 109
Physical structure of coal, 405
Piping system, fuel oil, **819**
Prime movers, 319
Problems of the petroleum industry, **1190**
alcohol as motor fuel, **1204**

Problems of the petroleum industry, chemical products from petroleum, **1207**
fuel oil substitute, **1205**
oil for gas manufacture, **1206**
of production, **1196**
of refinery technology, **1197**
production in U. S., **1191**
requirements of U. S., **1193**
shale oil, **1192**
substitutes for gasoline, **1202**
Producer gas, **914**
application of, **938, 980**
by-product recovery costs, **973**
carbonizing coal with, **989**
clean cold, **943**
cleaning from high volatile fuels, **946**
from low volatile fuels, **945**
cost hot raw, **967**
cost of, **964**
definition of artificial gases, **916**
for by-product oven heating, 179, 184
for forge work, **987**
hot and cold, **938**
hot raw, **941**
in automobile industry, **982**
influence of water vapor, **919**
plant layout for clean, **948**
tar extraction, **958**
Producer reactions, **917**
Producers, built-in, for heating by-product coke ovens, 182
Crossley Bros., 335
Duff, 335
history, 330
Lymn, 338
mechanical, 337
Quintin Moore, 336
superheater, 342
Production problems in the petroleum industry, **1196**
Providence Gas Co. by-product ovens, 184
Pulverization of coal, 163
Pulverized coal, **683**, 701
See also Coal, Pulverized
See also Fuel, Pulverized
Allis-Chalmers coal feeder, **652**
Am. Locomotive Co. System, **656**
Anaconda burner, **662**
Arrowwood multi-mix system, **652**
Bergman system, **661**
boilers fired with, **675**
burners, feeders, and mixers, **647**
chemical reactions in flame of, 555
chemistry of, **683**
combustion of, **683**
comparison with stokers, **711**
consumption, 556
control of temperature, **690**
effect of furnace temperature on ash, **692**
fine ash, **686**
firing of boilers, **675**
flames, **687**
Fuller induction type,
furnace volume, **693**
Garret-Cavers burner, **662**
Grindle system, **649**
Hanna-anthracite burner, **652**
Lopulco burner, **651**
low-pressure pneumatic feeder, **657**
pneumatic siphon controllers, **656**
pre-heating the air, **688**
Pruden carburetor, **655**
Quigley burner system, **649**
Renkin controller, **650**
single air supply, **661**
Stroud system, **648**
Pulverizers, Allis-Chalmers compeb mill, 598
American, 581
Aero, 582
ball and tube mills, 590

Pulverizers, Bonnet mill, 586
closed circuit grinding, 594
disc mills, 583
Fuller-Lehigh mill, 584
Hardinge conical mill, 601
high-speed mills, 580
Huntington type, 584
Kennedy-Van Saun mill, 588
tube mill, 599
McCool, 583
open circuit grinding, 593
Raymond impact, 581
roller mill, 587
ring roll mills, 583
Smidth tube mill, 597
Stroud, 581
types of, 580

Q

Quigley coal conveyor, **638**
system, use of pulverized fuel, 528

R

Radiant energy in surface combustion, **1071**
Radiation losses, **1123**
Railway electrification, 297
fuel, 296
locomotive operation, **1156**
Rankine cycle, 324
Refinery technology, problems, **1197**
Refractories industry, **1184**
Regulation of fuel oil, **803, 806**
Resins, coking, 404
Retorts, gas producer, 428
Ruggles-Coles dryer, 565

S

Sawdust briquets, **787**
Schniewind by-product coke oven, 147
Screen dust, 576
Screens, vibrating, 603
Semet-Solvay ammonia recovery process, 200
Separators, air, 578, 602
Shale oil, **1192**
Sheet mill furnaces, use of pulverized fuel, 527
Ship's fuel, oil, 295
Smoke, 77
Sodium silicate, 255
Specifications for fuel oil, **1242**
Specific heat of gases, 53
Spray tower, blast furnace gas, **1028**
Steam boilers, use of pulverized fuel, 518
Steamship fuel, 292
Steam tests with colloidal fuel, **895**
Steel, heat treatment, **1120**
Stills, ammonia, 195
Stokers, **757**
advantages of, **784**
American Stoker Co., **776**
Combustion Engineering Corp., **773**
comparison with pulverized fuel, **711**
Detroit, **767**
inclined grate underfeed, **778**
Jones, **771**
Lehigh, **764**
model automatic, **768**
Moloch, **774**
Murphy, **766**
overfeed inclined grate, **761**
side feed, **766**
Riley underfeed, **778**
Roach, **774**
side dumping underfeed, **771**
Stevens, **775**
Taylor, **778**
traveling or chain grate, **768**
types of mechanical, **757**
underfeed, **770**
Westinghouse, **769**
Roney, **762**
underfeed, **778**
Wetzel automatic, **763**
Stoke's law, **882**
Storage of coal, 167
of fuel oil, **802**
systems, coal, 561
Sub-bituminous coal, 5

Sulfite pitch, 254
Sulphur in coke, 111
Super-power stations, **1143**
Surface combustion, **1068**
bibliography of, **1091**
definition of, **1090**
early type of furnace, **1075**
excess air in, **1072**
high-pressure system, **1079**
mixing the gases, **1077**
perfect combustion mixtures, **1069**
radiant energy in, **1071**
tunnel burner, **1076**

T

Tar, coal, 353
Dayton gas, **1041**
extraction, producer gas, **958**
extractors, 193
formation from by-product coke ovens, 186
oils, character, 422
utilization of, 503
other uses for, 508
recovery of, 192
Temperature of combustion, 56
Transmission, electric power, 314, 1143
Transportation of fuel oil, **802**
Trees, **786**
Trent, amalgam, 293
distillation of, 479
process, 628
amalgamation of hydrocarbons, **633**
with oil, **629**
results of cleaning, **630**
utilization of products, **635**
washing and pulverizing, 628
Turbines, 298
possibilities of, 322

V

Volatile matter of coke, 107

W

Washers, vertical static, 339
Waste heat boilers, **1157**
Water gas, **995**
air blasting, **998**
by-products, 376
carbureted, **1007**
combination with coal gas, **1010**
continuous processes, 376
costs, **1012**
generator, rotary, 370
history of, **996**
modifications of, **1009**
process of manufacture, **1000**
properties of, **1005**
in standard generators, 375
steaming, **998**
theory of, **997**
Trent process, 374
Water power cost, **1139**
development, **1138**
resources of U. S. and Canada, 270
vs fuel, 271
Waterways, 311
Whirlers, blast-furnace gas, **1026**
Wood, preservation, 504
efficiency of, **791**
measuring, **790**
method of using, **790**
methods of selling, **789**
mill waste, **786**
producing and marketing, **788**
saw-dust briquetts, **787**
seasoning, **789**
supply of fuel wood, **787**
thinnings and improvement cuttings, **786**
transportation, **789**
trees, **786**
use of for fuel, **785**

Z

Zinc and tin, pulverized fuel, 555

THIS BOOK IS DUE ON THE LAST DATE
STAMPED BELOW

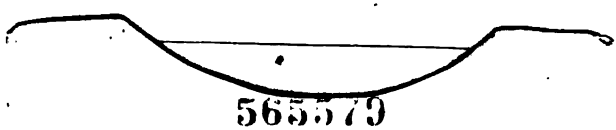
AN INITIAL FINE OF 25 CENTS
WILL BE ASSESSED FOR FAILURE TO RETURN
THIS BOOK ON THE DATE DUE. THE PENALTY
WILL INCREASE TO 50 CENTS ON THE FOURTH
DAY AND TO $1.00 ON THE SEVENTH DAY
OVERDUE.

SEP [illegible] '33
SENT ON ILL
JUL 2 6 1995
U. C. BERKELEY

LD 21-20m-6,'32

YC 33985

See Vol I



565579

Engineering
Library

UNIVERSITY OF CALIFORNIA LIBRARY